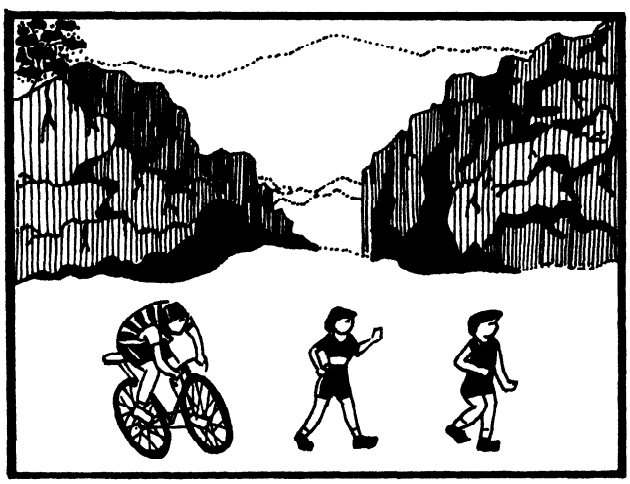
APS Conference

Integrative Biology of Exercise

Red Lion Hotel and
Sheraton Colorado Springs Hotel

Colorado Springs, Colorado
September 23–26, 1992



The American Physiological Society
The American College of Sports Medicine

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Integrative Biology of Exercise

September 23–26, 1993
Colorado Springs, Colorado

Wednesday, September 23	Thursday, September 24	Friday, September 25	Saturday, September 26
Symposium 3:00–6:00 pm Limiting factors for maximum aerobic performance: how do we define and test them? Chair: Stan Lindstedt	Tutorial 8:00–9:00 am Exercise in the diabetic Speaker: Edward Horton	Tutorial 8:00–9:00 am Protein polymorphism and muscle function Speaker: Richard Moss	Tutorial 8:00–9:00 am Metabolic integration during exercise Speaker: Bengt Saltin
Symposium 3:00–6:00 pm Body fluid homeostasis during exercise Chairs: Ethan Nadel and Carl Gisolfi	Tutorial 8:00–9:00 am Control of glycolysis in contracting muscle Speaker: Richard Connett	Minisymposium 8:00–9:00 Theories for the decreased maximal blood lactate level in chronic hypoxia Chair: Paolo Cerretelli	Tutorial 8:00–9:00 am Evolution of olympic performance Speaker: Per-Olof Astrand
Debate 7:00–8:00 pm Anaerobic threshold: evidence for and against Referees: Brian Whipp and John Reeves For: Karlman Wasserman Against: George Brooks	Symposium 9:00–Noon The lung at the limit of its function during exercise Chair: Brian Whipp	Symposium 9:00–Noon The PO_2 gradient from hemoglobin to cytochromes Chair: Peter Wagner	Symposium 9:00–Noon Neural control of the cardiorespiratory systems during exercise Chair: Jere Mitchell
	Symposium 9:00–Noon Control of lipid oxidation in contracting muscle Chair: Jeanie McMillin	Symposium 9:00–Noon Cellular bases of muscle adaptation Chair: Kenneth Baldwin	Symposium 9:00–Noon Human versus nonhuman models of exercise: what can we learn from animals? Chair: Jim Jones
	Symposium 3:00–6:00 pm Microvascular function in contracting skeletal muscle Chair: Brian Duling	Symposium 3:00–6:00 pm Cellular bases of skeletal muscle fatigue Chair: Robert Godt	Symposium 3:00–6:00 pm Regulation of respiration in striated muscle Chair: Martin Kushmerick
	Symposium 3:00–6:00 pm Muscle mechanics: from molecular crossbridges to intact animals Chair: Richard Taylor	Symposium 3:00–6:00 pm Effects of exercise training on the coronary circulation Chair: Harold Laughlin	Symposium 3:00–6:00 pm Exercise during physiological and pathophysiological states Chair: Gunnar Blomqvist
	Flying W Ranch 6:30–10:00 pm Dinner and entertainment	Banquet Lecture and Award Presentations 7:30 pm Featuring Sir Roger Bannister	

Sessions with Contributed Abstracts

Thursday

Friday

Saturday

The kind support of the Gatorade Sports Science Institute for the APS Conference: Integrative Biology of Exercise is gratefully acknowledged.

10.1

HEPATIC GLUCONEOGENESIS IS LIMITED BY PRECURSOR DELIVERY, NOT OXYGEN AVAILABILITY, DURING SEVERE REDUCTIONS IN FLOW. K.D. Sumida, J.H. Urdiales, and C.M. Donovan
Univ. So. Calif., Dept. Exer. Sci., Los Angeles, CA 90089

Reduced hepatic blood flow has been observed during exercise and proposed as a limitation for hepatic gluconeogenesis. Inherent in this reduced flow are decrements in precursor delivery and oxygen availability, both potential limitations for hepatic glucose output (HGO). To determine the limiting factor, ie. precursor delivery or oxygen availability, for hepatic gluconeogenesis, we utilized *in situ* perfused livers from 24 hr fasted rats. Following a 30 min 'washout' period with Krebs-Henseleit buffer, fresh bovine erythrocytes (Hct ~20%) and no substrate, steady-state perfusions were initiated with a 2nd reservoir containing lactate (2.5 mM or 4 mM) and glucagon (0.25 ug/ml). Hct was adjusted with erythrocytes (30% or 40%) to alter oxygen delivery or remained unaltered (20%). At 0.6 and 0.85 ml/min/g with 2.5 mM lactate, a significantly higher VO2 (umol/min/g) was observed for elevated Hcts 2.97 ± .17 compared to unaltered Hct, 1.93 ± .10. Relative HGO (umol/min/g) was not significantly different between elevated Hct (40%) and unaltered Hct at 0.6 ml/min/g, 0.47 ± .03 nor between elevated Hct (30%) and unaltered Hct at 0.85 ml/min/g, 0.66 ± .03, respectively. Raising the 2nd reservoir [LA] to 4 mM significantly increased HGO at 0.6 ml/min/g, 0.61 ± .04. VO2 was significantly higher for elevated Hcts, 3.32 ± .28, compared to unaltered Hct, 2.70 ± .03. HGO was unaffected by Hct level. Results indicate that during severe reductions in flow, *in situ* HGO is limited by precursor delivery, not oxygen availability.

10.2

INTERACTION AMONG CARBOHYDRATE TYPE AND CONCENTRATION AND SOLUTION OSMOLALITY ON FLUID ABSORPTION. X. Shi, S. Flanagan, R. W. Summers,* H. P. Schedl,* R. T. Chang* and C. V. Gisolfi, Depts. of Exercise Science and Internal Medicine. Univ. of Iowa, Iowa City, IA 52242.

A triple lumen tube with a 10 cm mixing segment and 40 cm test segment was positioned in the duodenojejunum. Using a randomized double-blind design, eight male subjects were perfused at the rate of 15 ml/min for 90 min. Quantity, type, and osmolality of the 6 carbohydrate (CHO) solutions were: a) 8% sucrose, 314 mOsm (S); b) 8% glucose, 534 mOsm (G); c) 8% maltodextrin, 226 mOsm (M); d) 4% G and 4% F, 521 mOsm (GF); e) 3% G, 3% F and 2% S, 486 mOsm (GFS); and f) 4% S, 2% G and 50 mM glycine (Gly), 347 mOsm (SGGly). [Na^+] and [K^+] were 19 and 3 mM, respectively. In the mixing segment, 5 of 6 solutions resulted in water secretion. In the test segment, water absorption was significantly less (a) from hypertonic G (84±114 ml/h/40 cm) than all other solutions except M (271±53 ml/h/40 cm), and (b) from M compared with GFS (511±39 ml/h/40 cm). Considering absorption from both mixing and test segments: (a) slightly hypertonic S (231±180 ml/h/50 cm) produced as much fluid absorption as hypertonic GF (223±87 ml/h/50 cm), (b) hypotonic M did not produce significantly more absorption than hypertonic GF, and (c) adding glycine to a SG solution (248±69 ml/h/50 cm) did not add to fluid absorption. We conclude that fluid absorption from CHO-electrolyte solutions depends on CHO type and concentration, and the osmolality of the solution. Supported by the Gatorade Sports Science Institute.

10.3

RAPID OROCOLONIC TRANSIT OF A SOLID MEAL IN CHRONICALLY ACTIVE PERSONS WITH HIGH ENERGY INTAKE. Alon Harris, John B. Watkins,* Carmen A. Yiamouyiannis, Joseph A. Near* and Bruce J. Martin. Indiana Univ. Sch. of Med., Indianapolis, IN and Med. Sci. Prog., Indiana Univ. Sch. of Med., Bloomington, IN 47405.

Increases in energy requirements and energy intake alter digestive strategy in several animal species. Whether similar intestinal adaptations to hyperphagia occur in humans remains unclear. A previous study (J. Appl. Physiol. 70(4): 1550-1553, 1991) showed that the hyperphagia of chronic exercise in humans was associated with accelerated orocecal transit of a liquid meal. This study investigated the influence of a chronic increase in energy intake on the transit rate of a solid meal from the mouth to the colon. Orocolonic transit was determined by using a HPLC assay for sulphapyridine. This technique employs the conversion of sulphasalazine to sulphapyridine and 5-aminosalicylic acid by microbial azoreductase present in the human colon. The sulphapyridine formed is absorbed into the circulation and detected in peripheral venous blood when transit occurs. Dietary records completed by the subjects for 3 days were analyzed for total calories, and proportions of fat, protein, carbohydrate and dietary fiber. Subjects were given a solid meal consisting of commercially available breakfast bars (250 Kcal) supplemented with 500mg sulfasalazine, with venous blood samples taken, thereafter, every 30 minutes. In 9 young healthy men with a wide range of energy intake (1763-5108 Kcal/day), resting mouth-to-cecum transit was faster in high caloric consumers ($r = -0.69$; $p<0.05$). Dietary fiber intake was also statistically correlated with energy intake ($r = -0.74$; $p<0.05$). We conclude that the hyperphagia of chronic exercise in humans may be linked with significant gastrointestinal adaptations.

10.4

ACETAMINOPHEN PHARMACOKINETICS: LACK OF DEPENDENCE UPON CALORIC INTAKE. Bruce J. Martin, Carmen Yiamouyiannis, Ruth Sanders,* Alon Harris, and John B. Watkins III.* Medical Sciences Program, Indiana University, Bloomington, IN 47405.

Recent evidence suggests that chronic physical activity and its associated hyperphagia provokes adaptations in intestinal transit time, hepatic biotransformation enzyme content, bile flow rate, and biliary clearance of certain test substances. Do these changes alter the pharmacokinetics of drugs? We approached this question by measuring acetaminophen pharmacokinetics in a group of healthy young males chosen to represent a wide range of chronic physical activity. Dietary records completed by the subjects for 3 days revealed that daily caloric intake in the 19 men ranged from 1683 to 5108 Kcal (21 to 65 Kcal/kg/day). Each subject ingested 1000mg acetaminophen in the fasting, resting state in the morning; antecubital venous blood samples were analyzed for acetaminophen by HPLC for 8 subsequent hours. We found little evidence that acetaminophen pharmacokinetics vary with caloric intake. There was no correlation of peak blood levels of the drug, half-life of the compound in plasma, or area under the plasma acetaminophen curve with caloric intake. There was a weak positive correlation of total clearance with calories ingested ($r = 0.47$, $p<0.05$). The independence of acetaminophen pharmacokinetics from energy intake was equally clear if the 19 subjects were considered in two groups, active and inactive. We conclude that enormous variation among humans in chronic physical activity and food intake fail to alter the intestinal absorption or clearance of acetaminophen from blood.

ACID-BASE BALANCE

11.1

CARBONIC ANHYDRASE III IN CO_2 TRANSPORT IN CELL-FREE MEDIUM. P. Virtanen*, H.K. Väänänen* and T.E.S. Takala* (SPON: V. Kovanen). Univ. of Oulu, SF-90220 Oulu, Finland.

The role of carbonic anhydrase III (CA III) in the facilitation of CO_2 transport was examined in the extracts of soleus, tibialis anterior, vastus lateralis and cardiac muscle of rat. The facilitation of the CO_2 transport depended on the CA III concentration of the extracts being highest in the soleus extract and less pronounced in the tibialis anterior extract. In the vastus lateralis and cardiac extracts there was no facilitated transport. Purified CA III and CA II accelerated CO_2 transport almost as much in equimolar concentrations although the specific hydratase activity of CA II is more than 100 times greater than that of CA III. The data suggests that the concentration but not the hydratase activity is the rate limiting factor in the facilitation of CO_2 transport by the carbonic anhydrases. Inhibition of the facilitated transport in soleus extracts with acetazolamide gave a K_I value of $1.5*10^{-3}$ M, which further confirmed the involvement of CA III in the CO_2 transport. The CA III facilitated CO_2 diffusion was considerably suppressed in polyacrylamide gels. The results suggest that part of CO_2 could be transported bound to the active site of diffusing CA III.

11.2

ORIGINS OF FEMORAL VENOUS ACID-BASE CHANGES DURING EXERCISE AFTER GLYCOGEN DEPLETION
M.I. Lindinger, G.J.F. Heigenhauser, L. Lands, R.S. McKelvie, E. Hultman*, L.L. Spriet, T. Putnam, and N.L. Jones. Dept. of Medicine, McMaster University, Hamilton, Ontario, Canada, L8S 4J9

This study examined changes in femoral venous plasma ion and acid-base status during prolonged exercise under normal (NC) or glycogen depleted (GD) conditions. In 2 trials separated by 1-2 weeks 4 healthy males in NC or GD state cycled at 75% of peak VO_2 for 50±7 min (exhaustion for GD). Blood was sampled from a catheter placed in the femoral vein. Plasma [H^+] rose by 20±2 nM (NC) and 23±3 nM (GD) at 5 min of exercise from 42±1 nM (NC) and 45±2 nM at rest. In NC [H^+] remained high until 50 min, but in GD decreased by 17 nM by exhaustion. Increases in [H^+] were due to increases in plasma [proteins] and PCO_2 (NC and GD) and decreases in the strong ion difference [SID] (NC only). PCO_2 rose from 49±3 mmHg (NC) and 42±1 mmHg (GD) at rest to 71±4 mmHg (NC) and 61±8 mmHg (GD) at 5 min and 64±2 mmHg (NC) and 57±4 mmHg (GD) at 50 min. In both trials [HCO_3] did not change from rest. In NC, after 5 min of exercise [SID] decreased 4.5 mEq/l from 39.8±0.4 at rest but [lactate] rose by 11±2 mM. The discrepancy between these 2 changes was made up by a 5 mM rise in [Na^+], 1.4 mM rise in [K^+] and a 1 mM drop in [Cl^-]. But in GD [SID] did not change despite a rise in [lactate] from 1 to 9.9±2.8 mM and 5.3±1.5 mM at 5 and 50 min. The rise in [lactate] was balanced by a 5-6 mM rise in [Na^+] and a 1.5 mM rise in [K^+] at both 5 and 50 min; [Cl^-] did not change. Supported by the Medical Research Council and the Natural Sciences and Engineering Research Council of Canada.

11.3

EFFECT OF CHRONIC ACETAZOLAMIDE ON GAS EXCHANGE AND ACID-BASE CONTROL AFTER MAXIMAL EXERCISE. J.M. Kowalchuk, G.J.F. Heigenhauser, J.R. Sutton and N.L. Jones. Dept. Medicine, McMaster Univ., Hamilton, Ont., Canada, L8N 3Z5.

The interaction between systems regulating acid-base balance (i.e. CO_2, strong ions, weak acids) was studied in 6 subjects for 10 min following 30s maximal isokinetic cycling during control (CON) and after 3 days acetazolamide (ACZ) administration (500 mg/8 hr p.o.) to inhibit blood carbonic anhydrase (CA). Gas exchange was measured; arterial and forearm venous blood were sampled for acid-base variables. Muscle power output was similar in ACZ and CON, but peak recovery $\dot{V}O_2$ was lower in ACZ; peak $\dot{V}CO_2$ was also lower in ACZ (2207 ± 220 ml/min) than CON (3238 ± 87 ml/min). $PaCO_2$ was lower at rest and the fall in $PaCO_2$ after exercise was delayed in ACZ. A higher [SID]a (Σ[cations] - Σ[anions]) was seen in ACZ during the first part of recovery and was due to a higher *$[Na^+]$a and $[Cl^-]$a, and* lower $[K^+]$a and $[La^-]$a. A-V differences across the forearm showed a similar uptake of Na^+, K^+, Cl^- and La^- in ACZ and CON. $[H^+]$a was higher and $[HCO_3^-]$a was lower in ACZ. Compared to CON, a-v $[H^+]$ was similar and a-v $[HCO_3^-]$ was lower in ACZ. CA inhibition impaired the removal of CO_2 by the lungs and inactive muscle and altered the equilibration of strong ions. Although $[La^-]$a was lower in ACZ, La uptake was similar, suggesting a greater oxidation by inactive muscle.

Supported by the Medical Research Council of Canada

11.4

K^+ REDISTRIBUTION DURING EXERCISE IN MAN. Jostein Hallén*, Lars Gullestad* and Ole M. Sejersted. National Inst. of Occupational Health, 0033 Oslo, Norway.

The rise in plasma $[K^+]$ during exercise with a large muscle mass might be pronounced since little resting muscles is accessible for redistribution. One group (n=5) bicycled (BC) at 37 W (10-15 kg muscles) and another group (n=5) did dynamic knee-extension (KE) at 25 W (4-5 kg muscles). $[K^+]$ was measured in the femoral vein by K^+-selective electrodes and in arterial blood samples. Leg blood flow was measured by bolus injection of indocyanine green. Initial rates of rise and peak venous $[K^+]$ were not different, and after 4 min K^+-release was 0.13 and 0.11 in the BC and KE groups (ns). Even so, arterial $[K^+]$ rose by 0.20 mmol/l in the BC group compared with 0.39 mmol/l in the KE group ($p<0.05$). By calculation 0.42 mmol more K^+ was redistributed in the KE group. Thus contrary to the hypothesis, redistribution of K^+ significantly attenuates the rise in arterial plasma $[K^+]$ during BC but not during KE.

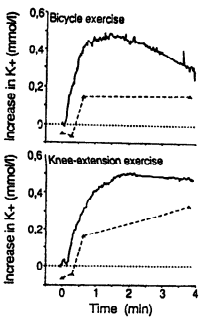

***Figure:** Change in $[K^+]$ in femoral vein (unbroken line) and artery (broken line)*

11.5

BLOOD ELECTROLYTE STATUS FOLLOWING POTASSIUM BICARBONATE INGESTION IN HUMAN SUBJECTS. T.W. Franklin*, L. Lands, P. Pedersen, D.G. Welsh*, G.J.F. Heigenhauser and M.I. Lindinger. School of Human Biology, University of Guelph, Guelph, Ontario, Canada, N1G 2W1.

This study examined the time course and characteristics of recovery from altered blood electrolyte status following oral potassium bicarbonate ($KHCO_3^-$) ingestion at rest. Five healthy male subjects ingested 3.57 mmol/kg $KHCO_3^-$ in a 600 mosmol/L solution. Arterial blood (brachial a.) and antecubital venous blood was sampled at 10 and 30 min during a pre-ingestion rest period (PRE), at 10 min intervals during a 60 min ingestion period, and at 10,15 and 30 min intervals during a 210 min post-ingestion recovery period (POST). Initial arterial $[K^+]$, $[Na^+]$, and $[Cl^-]$ were 4.25 mM, 143.2 mM and 106.1 mM respectively. $[K^+]$ was maximally elevated to 7.17±0.12 mM at 50 min POST, and a net uptake of 1.0 mM across the forearm occurred. After 210 min POST, $[K^+]$ was still elevated at 5.10±0.35 mM and the a-v diff. was reduced to 0 mM. $[Na^+]$ and $[Cl^-]$ decreased to 140.9±0.34 mM and 104.3±0.33 mM respectively at 60 min POST. After 210 min POST, $[Na^+]$ and $[Cl^-]$ had not returned to PRE levels. An alkalosis was present with arterial $[H^+]$ decreasing to 33.8±1.6 nM at 30 min POST, from 39.3 nM PRE; and arterial $[HCO_3^-]$ increasing to 30.4±1.06 mM at 40 min POST from 24.2 mM PRE. There was no change in arterial PCO_2. It is concluded that the tissues minimized the extent of the hyperkalemia by rapidly taking up K^+ from the arterial blood, presumably through K^+ induced stimulation of Na^+-K^+ ATPase activity. Blood electrolyte status was also influenced, but more slowly, by K^+, Na^+, and Cl^- losses at the kidney. Supported by NSERC of Canada and MRC.

11.6

GLYCOGEN DEPLETION RESULTS IN ALTERED ION AND ACID-BASE STATE DURING EXERCISE. G.J.F. Heigenhauser, M.I. Lindinger, R.S. McKelvie, L. Lands, E. Hultman, L. Spriet, T. Putnam and N.L. Jones. Dept. of Medicine, McMaster University, Hamilton, Ontario, Canada, L8S 4J9

This study compares the origins of the arterial plasma acidosis seen during prolonged exercise in normal (NC) vs glycogen depleted (GD) conditions. In 2 trials separated by 1-2 weeks, 4 healthy males, either NC or GD, cycled at 75% of peak VO_2 until exhaustion (50±7 min for GD) or until the GD exhaustion time in NC. Blood was sampled from a catheter placed in the brachial artery. Arterial plasma $[H^+]$ rose from 39.1±0.1 nM (NC) and 42.9±0.3 nM (GD) at rest to 49±3 nM (NC & GD) at 5 min and then decreased to 45±3 (NC) and 39±4 nM (GD) at 50 min. In NC the acidosis persisted throughout exercise, but in GD $[H^+]$ returned to 41±1 nM by 30 min and 39±4 nM at 50 min. The rise in plasma [protein] was similar in both trials and contributed <5% to the acidosis. A 5 mmHg decrease in PCO_2 partially offset the acidifying effects of increased [protein] and decreased strong ion difference ([SID]). In NC the drop in [SID] from 38.2±0.3 to 29.5±1.4 mEq/L after 5 min of exercise was primarily due to an 11.3±1.2 mM rise in [lactate]. About 2-3 mEq/l of the rise in [lactate] was offset by increases in $[Na^+]$ (1-2 mEq/l) and $[K^+]$ (1.3 mEq/l); $[Cl^-]$ remained unchanged. In contrast, in GD increases in [lactate] consistently accounted for the changes in [SID] as 3 mM increases in $[Na^+]$ and $[Cl^-]$ balanced each other. Associated changes in $[HCO_3^-]$ in both trials were 30-40% less than the equivalent changes in [SID] and [lactate].

Supported by MRC and NSERC of Canada.

11.7

EFFECTS OF PRIOR EXERCISE OR CHEMICALLY INDUCED ACIDOSIS ON SUBSEQUENT MUSCULAR STRENGTH AND ENDURANCE. Douglas G. Bell*, Tom M. McLellan and Ira Jacobs. DCIEM, Toronto, Ont., M3M 3B9

Muscular fatigue is linked with a decrease in blood pH. To further clarify this association, this study compared the effects of two means of inducing acidosis on a subsequent criterion task (CT) of muscular strength and endurance. Acidosis was induced in 8 subjects prior to the CT by ingesting 0.3 g/kg ammonium chloride (AC) for one trial, by upper body exercise (UBE) for another trial, while a third trial occurred after placebo (PL) treatment. Strength (S) was evaluated as force generated during a maximum voluntary contraction (MVC) of the quadriceps. Muscular endurance (E) was the integration of force generated during a 45-s MVC. Electrical stimulation (interpolated twitch technique) of the quadriceps was done during the CT to evaluate the extent of voluntary motor unit recruitment. The acid-base status of arterialized whole blood samples was assessed before and after the CT. The results showed that pH was significantly decreased to a similar extent by both AC (7.26) and UBE (7.24) compared with PL (7.41). S was not affected by the experimental treatments but E was significantly and similarly reduced (6.5%) by both AC and UBE. In addition the electrical stimulation indicated that neither UBE nor AC resulted in an impairment of voluntary motor unit recruitment. The data suggest that the impairment observed in E occurs distal to the motor end plate and is independent of the mode of acid-base manipulation.

11.8

PRESERVATION OF THE ICF PROTEIN BUFFER SYSTEM DURING ACUTE METABOLIC ACIDOSIS. M.L. Halperin, J. Goguen, C. Bun-Chen and S. Cheema-Dhadli. Renal Division, St. Michael's Hospital, Toronto, Canada.

Buffering is carried out by both the bicarbonate (bic) buffer system (BBS) and the non-BBS (largely intracellular proteins). We have recently shown that most buffering of a modest acid load occurs on the BBS (acute HCl load to lower [bic] to 14 mmol/l was buffered, 50 % via the ECF BBS and 50 % via the non-BBS (AJP 262:R305-309, 1992). When the Pco_2 was lowered to 30 mm Hg, the ICF non-BBS was back-titrated so that 98% of protons were now buffered by the BBS, 2/3 in the ECF and 1/3 in the ICF. The purpose of this study was to evaluate whether hormones such as insulin also affect the distribution of protons between the BBS and non-BBS during metabolic acidosis as this hormone may lead to an alkalinization of the ICF. Chronic metabolic acidosis was induced in 12 dogs (fed 5 mmol NH_4 Cl bid x 5 days) ([bic] 13 ± 1 mmol/l, pH 7.28 ± 0.01). Sixty min after 1 U/kg of insulin was infused, the acidosis became more severe ([bic] 9 ± 1 mmol/l, pH 7.27 ± 0.01). There was no net appearance of organic acids nor loss of $NaHCO_3$; hence protons seemed to have shifted from the ICF to the ECF. When the quantity of bic titrated in the ECF was replaced acutely (16 mmol), the [bic] rose acutely back to 13 mmol/l (small volume of distribution). Further infusion of another 16 mmol bic led to only a marginal rise in the [bic] (large volume of distribution). We conclude that buffering of protons by the ICF non-BBS depends not only on the proton load, but more importantly on changes in the Pco_2 and hormonal influences (H^+ ions can be exported).

12.1

BLUNTED REHYDRATION RESPONSE IN OLDER MEN. C.A. Weseman*, G.W. Langhans*, H. Scherzer*, G.W. Mack and E.R. Nadel. J.B. Pierce Lab and Yale Univ., New Haven, CT 06519, New Britain General Hospital, New Britain, CT 06053

To test the hypothesis that older men (65+) have a diminished drive to rehydrate after a thermal/exercise-induced dehydration, we studied twelve 65+ (65-79 yr) and six young subjects (Y) (19-25 yr) during 3 h recovery from 105 min of a heat [360C, <30% RH] and exercise (70% age-predicted maximal heart rate) protocol, which elicited a 2.3% and 3.0% decrease in body weight in 65+ and Y, respectively. After dehydration, subjects rested at 28^{0}C without fluids for 30 min to allow body fluid compartments to stabilize. Plasma volume (PV), plasma osmolality (Posm), urine volume and thirst were measured pre and post exercise and during rehydration. Baseline PV (Evan's Blue) was not different between groups whereas Posm was higher in 65+ than Y (287±1 vs 281±2 mosm/kg) (P<0.05). Thirst ratings at rest were significantly lower in 65+ than Y, despite higher Posm. During dehydration, PV decreased by 5% and 6% while Posm increased to 292±1 and 289±1 mosm/kg in 65+ and Y, respectively. Perceived thirst increased in both groups during dehydration yet remained significantly higher in Y throughout. Fluid intake (ad libitum tap water) during the next 3 h was greater in Y than 65+ (16.6±4.1 vs 8.9±2.0 ml/kg) (P<0.05), resulting in a net fluid gain of 12.7±2.6 and 6.3±2.1 ml/kg in Y and 65+, respectively. PV was restored to 98% of control by 3 h rehydration in both groups. The change in thirst per unit change in Posm in 65+ was 40% of that in Y. Because the relation between fluid intake and thirst was identical between 65+ and Y, we concluded that the blunted rehydration in older men is related to a lower overall sensation of thirst to a given Posm, resulting in diminished fluid intake.

12.2

RENAL RESPONSES TO DEHYDRATION-REHYDRATION IN OLDER MEN. G.W. Mack, C.A. Weseman*, G.W. Langhans*, H. Scherzer*, and E.R. Nadel. J.B. Pierce Lab, Yale Univ., New Haven, CT 06519, New Britain General Hospital, New Britain, CT 06053

The renal responses to a thermal/exercise induced dehydration which elicited a 2.3-3.0% decrease in body water, and 3 hr of rehydration with tap water were studied in 12 older men (65+,65-79 yr) and 6 young subjects (Y, 19-25 yr). Before and after dehydration subjects rested at 28^{0}C without fluids for 30 min to allow body fluid compartments to stabilize. Dehydration induced by 105 min of heat [36^{0}C, <30% RH] and exercise (70% age-predicted maximal heart rate) caused plasma volume to decrease by 5- 6% and plasma osmolality (Posm) to increase 6-7 mosmol/kg. Following dehydration, free water clearance (CH_2O) averaged -0.64±0.15 and -0.57±0.13 ml/kg/min for Y and 65+, respectively while urine osmolality was greater in Y than 65+ (969±65 vs. 816±66 mosmol/kg) suggesting a reduced ability to concentrate urine following dehydration in 65+ subjects. During rehydration (fluid intake =16.6±4.1 in Y and 8.9±2.0 in 65+) plasma aldosterone (ALDO) decreased from 303±66 to 140±28 pg/ml and 140±28 to 86±8 pg/ml in Y and 65+, respectively. The relationship between the urine Na^+/K^+ ratio or fractional Na^+ reabsorption and ALDO was similar for Y and 65+ during dehydration and rehydration. During rehydration, CH_2O increased 0.25±0.99 ml/kg/min for Y due to a decrease in Posm and presumably a decrease in plasma antidiuretic hormone (ADH) but was unchanged for 65+ (-0.59±0.18 ml/kg/min). The increase in CH_2O per unit reduction in Posm during drinking was 6 times greater in Y than 65+. The blunted renal responses to dehydration and drinking in 65+ cannot be explained by changes in ALDO and probably reflect altered reflex control of ADH release or reduced renal sensitivity to circulating ADH.

12.3

A COMPARISON OF FLUID, METABOLIC, AND PERFORMANCE INDICATORS: 200 YD FREESTYLE SWIMS IN EUHYDRATED AND HYPERHYDRATED STATES. M.F. Bergeron*, R.W. Kenefick*, C.M. Maresh, & L.E. Armstrong. Human Performance Laboratory, The University of Connecticut, Storrs, CT 06269-1110

Hydration status has not been emphasized or extensively examined in swimming. Thirteen (6♀, 7♂) collegiate swimmers swam two 200 yd time-trials (3 d apart) in alternate euhydrated (**E**) and hyperhydrated (**H**) states. Preexercise plasma osmolality (**E**:288.4 & **H**:284.9 $mmol \cdot kg^{-1}$; p<.001) and urine specific gravity (**E**:1.022 & **H**: 1.011; p<.001) values distinguished the hydration status of the swimmers. There were no differences (p>.05) in postexercise plasma volume (**E**:-16.4 & **H**:-17.9%Δ), plasma lactate (**E**:18.8 & **H**:17.8 $mmol \cdot l^{-1}$), plasma glucose (**E**:5.26 & **H**:5.34 $mmol \cdot l^{-1}$), heart rate (**E**:167.1 & **H**:165.2 $beats \cdot min^{-1}$), or perceived exertion responses. Performance time improved for 8 swimmers during **H**, but was not statistically significant (p>.05), perhaps due to the wide ability range of this group (**E**:108.7 to 133.6 s). These data demonstrate that hyperhydration had no performance advantage over euhydration, for this group, during a 200 yd time-trial swim.

12.4

MEASUREMENT OF TOTAL BODY WATER BY CHANGING OSMOLALITY.

M.T. Hamilton, P.D. Watson, & D.S. Ward, Dept. of Exercise Science & Physiology, U. of South Carolina, Columbia, SC 29208.

Measurement of total body water (TBW) is essential to understanding mechanisms determining fluid balance during adaptation to exercise or environmental stress. Unfortunately, there are few studies measuring TBW because existing techniques are not readily accessible to many laboratories. The purpose of this pilot study was to develop a rapid and inexpensive technique of measuring TBW. The method is based on the principle that change in osmolality in body fluids after adding a mass of osmoles is dependent on TBW. From plasma osmolality before (O_1) and 20 min. after (O_2) adding a small volume (ΔV, 9-21 ml) of hypertonic saline (osmolality O_A, ~5 mOsm/ml), we calculated TBW in 5 fasted cats from $TBW = \Delta V(O_A - O_2)/(O_2 - O_1)$. TBW was 59.8 ± 5.5% (SD) of body weight (range 55-68%) which is similar to literature values. Two animals were sacrificed and dried to constant weight. This drying approach gave values of 55.2 and 59.0%, compared to 54.8 and 56.2% by the new method. We conclude that changing osmolality is a rapid and inexpensive method for measurement of TBW.

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12.5

SODIUM APPETITE AND BODY FLUID REGULATION IN HUMANS. A. Takamata*, G.W. Mack, C.M. Gillen*, C.A. Weseman*, G.W. Langhans*, and E.R. Nadel. J.B. Pierce Lab. and Yale Univ. Sch. Med., New Haven, CT 06519.

To test the hypothesis that humans can demonstrate a sodium appetite, we measured body fluid and electrolyte balance, subjective taste responses to different NaCl solutions, and plasma aldosterone (Pald) and arginine vasopressin (Pavp) levels during acute Na^+ deprivation. Acute Na^+ deprivation was produced by intermittent exercise in heat (8 bouts of 30 min exercise [110-120 HR], with 15 min recovery periods, at 35°C), followed by 1-h recovery without water intake. This protocol produced a net Na^+ and water loss of 250 meq and 1.8 liter, respectively, an elevation in plasma Na^+ concentration ($[Na^+]p$) by 3.5 meq/kgH_2O and a decrease in plasma volume (PV) by 10 % from control. During the following 24 h, subjects drank tap water ad libitum and were provided a Na^+-free diet. $[Na^+]p$ decreased during rehydration, and was 3 meq/kgH_2O lower than the control between 6 and 24 h rehydration. PV increased during rehydration, but it remained reduced by 5% from the control until the end of the experiment. Urinary H_2O and Na^+ excretion decreased from 1.7 ml/min and 148 µeq/min at control to 0.6 ml/min and 11 µeq/min at 24 h rehydration, respectively. Pavp and subjective thirst increased after exercise and rapidly decreased during rehydration. Elevated Pald after exercise was reduced with drinking, but increased again between 6 and 24 hr rehydration. Ratings of salt taste palatability to concentrations of NaCl >0.1M decreased after exercise, and increased in response to the decrease in $[Na^+]p$ during rehydration. Thus, in addition to the marked increase in renal Na^+ reabsorption stimulated by elevated Pald, acute Na^+ deprivation lowered the aversion rating to concentrated NaCl solutions. This observed "sodium appetite" was preceded by increased thirst and may contribute to the regulation of extracellular volume.

12.6

RED CELL AND PLASMA VOLUME REGULATING HORMONES DURING AND AFTER EXERCISE AT HIGH ALTITUDE. W. Schmidt*, H. Spielvogel*, R. Penaloza*, A. Quintela* (SPON: G. Gros) Medizinische Hochschule Hannover, Germany and Instituto Boliviano de Biologia de Altura, La Paz, Bolivia.

Methods: To determine combined influences of exercise and chronic inspiratory hypoxia on plasma erythropoietin (EPO), atrial natriuretic peptide (ANP), and aldosterone (Aldo) level eight bolivian natives from 3700 m (BN) and ten lowlanders (Germany, 50 m; LL) were investigated during and after a 60 min lasting cycle ergometer test at 60 % of their maximal performance in their normal environment. Results: At rest [EPO] did not differ, whereas [ANP] was higher and [Aldo] was lower in the altitude group, respectively (ANP: BN 75.0 + 31.5; LL 30.8 + 17.4 pg/ml; Aldo: BN 53.4 + 14.1 , LL 171.2 + 50.1 pg/ml). EPO decreased in BN up to five hours after exercise (-1.6 + 0.2 mU/ml) and increased thereafter (24 h) in both groups (BN +1.6 + 1.2, LL +1.8 + 1.6 mU/ml). [ANP] and [Aldo] similarly increased during exercise in both groups (ANP: BN +56.1 + 17.3, LL +36.5 + 17.6 pg/ml; Aldo: BN +282.0 + 125.1, LL +304.1 + 70.6 pg/ml) and returned to the initial values one hour (ANP) or 24 hours later (Aldo). Plasma volume during exercise decreased more in BN (-11.8 + 3.3 %) than in LL (-6.4 + 3.9 %), but 48 h after exercise it increased to a higher level in LL. Conclusions: 1. Exercise does not directly stimulate [EPO], but has even suppressive effects at high altitude. 2. The different basal ANP and Aldo levels possibly affect changes in PV during and after exercise, which may be one cause for the lower arterial blood pressure in BN (RR_{sys} at rest: BN 104 + 11, LL 119 + 9 mm Hg; exercise: BN 127 + 10, LL 138 + 8 mm Hg).

12.7

ESTROGEN REPLACEMENT IN MIDDLE-AGED WOMEN AFFECTS THE REGULATION OF BODY FLUID AND ELECTROLYTES DURING EXERCISE. D. Zappe*, C.G. Tankersley*, W.C. Nicholas*, D.R. Deaver*, and W.L. Kenney. The Pennsylvania State University, Laboratory for Human Performance Research, University Park, PA 16802.

Blood volume is expanded during the menstrual cycle and pregnancy when circulating levels of estrogen are elevated. We examined the effects of estrogen replacement therapy (ERT) in 5 middle-aged (48±2 yr; $\dot{V}O_2max$=29±2 ml·kg^{-1}·min^{-1}) women in altering the regulation of body fluid homeostasis during a heat (T_{db}=36°C; T_{wb}=27.5°C) and exercise (≈40%$\dot{V}O_2max$) challenge. Plasma volume (PV) was estimated by a CO-rebreathing technique before ERT and 14-23 days after ERT. Venous hematocrit (Hct), hemoglobin concentration ([Hb]), plasma protein ([TPP]), aldosterone ([Aldo]), prolactin ([Prl]) and osmolality (P_{Osm}) were measured at rest and during exercise. At the end of exercise sweat samples were obtained from the hand and were analyzed for osmolality (S_{Osm}) and sodium concentration (S_{Na+}). Plasma estradiol-17β levels were elevated ($p<0.05$) following ERT compared to pre-ERT with little change in progesterone ($p>0.05$). Hemodilution occurred following ERT evidenced by a lowering of Hct and [Hb] with an expansion of PV (≈200ml) ($p<0.05$), with little influence on [TPP] or P_{Osm} ($p>0.05$). No change ($p>0.05$) occurred in *plasma [Prl] and [Aldo]* levels with respect to ERT at rest or during exercise although the S_{Osm} and S_{Na+} were reduced ($p<0.05$) at the end of exercise. These data suggest that in middle-aged women, ERT is associated with an effective hemodilution at rest and sweat electrolyte conservation during exercise.

12.8

THE COMBINED EFFECT OF NON-STEROIDAL ANTIINFLAMMATORY DRUG (NSAID) TREATMENT AND EXERCISE ON PROSTAGLINDIN (PG) SYNTHESIS. Y. Weinstein, Z. Reichard*, A. Danon* and B. Falk. The Ribstein Research Center, Wingate Institute, and Ben Gurion University Medical School, Beer Sheva, Israel.

The purpose of this study was to assess the combined effect of NSAID treatment and sub-maximal exercise on urine PG values. Twelve healthy non-smoking adult male subjects were treated orally by NSAID (Diclofenac 50mg, E group) and by placebo (C group) 1h before exercise. Treatment was performed in a random (counter-balanced) single-blind design. Subjects ran for 30 min at 70% VO_2max. Urine concentrations of PGE_2 and 6-keto $PG_{1\alpha}$ (the latter reflecting PGI_2) were analyzed before and 1h following treatment (immediately before exercise), as well as immediately and 1h following exercise. As expected, treatment resulted in a decrease in mean (±SE) 6-keto $PG_{1\alpha}$ (ng·ml^{-1}) values in E but not in C (334±5 to 42±2 vs. 288±5 to 212±3, respectively). Exercise resulted in an increase (E:382±5, C:290±4) and recovery resulted in a decrease (E:74±2, C:71±1) in 6-keto PG_1 values in both groups. A similar pattern was observed for PGE_2 concentrations. Contrary to expectations, NSAID treatment did not inhibit the increase in PG concentrations usually observed following exercise. We suggest that, under the conditions of this study, NSAID is not detrimental to PG synthesis, and thus, does not impair RBF during exercise.

12.9

HEMATURIA, PIGMENTURIA, AND PROTEINURIA IN EXERCISING HORSES. H. Schott*, D. Hodgson, and W. Bayly* College of Vet. Med., Wash. St. Univ., *Pullman*, WA 99164.

The effects of exercise on urinary excretion of red blood cells, pigments and protein were studied in mares performing treadmill exercise at speeds eliciting 40, 60, and 95% of the maximal oxygen consumption ($\dot{V}O_2max$). Gross hematuria and pigmenturia were observed in all horses during exercise at the two higher intensities, while these findings were detected in only 1 of 8 mares during exercise at 40% of the $\dot{V}O_2max$. Reagent strip analysis revealed microscopic hematuria/pigmenturia in the remaining 7 mares exercised at 40% of the $\dot{V}O_2max$. An increase in urine flow ($\dot{V}$) during exercise at 40% of the $\dot{V}O_2max$ likely contributed to the infrequent observation of gross hematuria and pigmenturia. In contrast, V decreased during moderate and high intensity exercise but increased dramatically for a short period following exercise. This resulted in rapid resolution of gross hematuria and pigmenturia following exercise at 60 and 95% of the $\dot{V}O_2max$, although microscopic hematuria/pigmenturia persisted for up to 60 min. Urinary protein excretion ($U_{prot}\dot{V}$) increased from a resting value of 4.8 ± 0.4 ml·kg^{-1}·min^{-1} to 32.0 ± 10.3 and 177.4 ± 42.0 ml·kg^{-1}·min^{-1} after exercise at 60 and 95% of the $\dot{V}O_2max$, respectively. $U_{prot}\dot{V}$ was no different from the resting value following exercise at 40% of the $\dot{V}O_2max$. Exercise-induced hematuria, pigmenturia, and post-exercise proteinuria appear to be common in horses. Their occurrence is related to exercise intensity but appears to be transient and without lasting changes in renal function.

Supported by the Washington State Equine Research Program.

12.10

RENAL RESPONSE TO HALF-MARATHON RACE WITH SPECIAL REFERENCE TO HEMATURIA AND PROTEINURIA. Hakan Gür Selçuk Küçükoğlu* and Esma Sürmen Sports Medicine Dept. of Medical Faculty University of Uludağ. Bursa, Türkiye

Hematuria and proteinuria have been noted in athletes after heavy exercise. To observe the effects of distance running on renal response; fresh urine specimens were obtained from 45 marathon runners 2 hours before and immediately after the half marathon race. All samples were analyzed for glucose, bilirubin, ketones, specific gravity, blood, protein urobilinogen nitrite, and leucocytes using Multiple Reagent strips (Ames, Miles Lab.Lmt, England) and urine sediment analysis.

All prerace amples were normal but 24 (53,3 %) of 45 postrace urine analysis showed hematuria of which 11 (24.4 %) were trace, 8 (17.8 %) were small 4 (8.9 %) were moderate, and 1 (2.2 %) was large. In addition, 33 (73.3 %) of postrace urine analysis showed proteinuria, 13 (28.9 %) of them were 30 g/l, 14 (31.1 %) of them were 100 g/l and 6 (13.3 %) were > 300 g/l. There were also leucocytes in 6 (13.3 %) ; bilirubin in 4 (8.9 %) and ketones in 3 (6.7 %) postrace urine samples.

It can be concluded that intensive running conditions as a half-marathon race or training for it may result in athletic anemia and protein depletion. Finally, we recommend to distance runners to supply their athletic anemia and protein depletion for a better performance.

THERMOREGULATION

13.1

IS EXERCISE INDUCED CUTANEOUS VASODILATATION MEDIATED BY CAPSAICIN SENSITIVE NERVES? Richard G.D. Roberts* and Roderick A. Westerman *(SPON: M. Hargreaves). Dept. of Physiology, Monash Univ., Clayton, Victoria 3168, Australia.

The neurotoxin capsaicin desensitises the skin by impairing the function of a specific group of C-fibres i.e. a sub-population of the polymodal nociceptors. The suggestion that sympathetic post-ganglionic C-fibres may also be capsaicin sensitive has been tested in the following experiment. Topical application of capsaicin (0.4% in ointment) was continued over 5 days to a small area of skin (30cm^2) of the proximal third of the volar surface of the forearm in 12 normal consenting volunteers. Within 24 hours of the cessation of this regimen a battery of tests was used to assess the degree of desensitisation achieved. These tests included measurement of neurogenically evoked axon reflex vasodilatory response by laser Doppler flowmetry and thermal thresholds from the affected skin and indicated that on average, significant desensitisation had been achieved, compared with normal skin. The subjects then carried out 12min of exercise in a heated room, on a Monark cycle ergometer - 4 stage x 3min continuous from 75-125Watt - during which time blood flow in both capsaicin treated and adjacent normal skin was recorded simultaneously by a 2 channel Moor MF3 laser Doppler flowmeter. There was no significant difference in the average increase in skin blood flow in capsaicin treated skin compared with normal skin. We concluded therefore that this regimen of capsaicin application significantly affects nociceptor function without impairing activity of sympathetic vasodilator fibres.

13.2

CONTROL OF RESPIRATORY EVAPORATION DURING EXERCISE IN SHEEP. R.E. Rawson*, D. Robertshaw, P.L. Entin*. Department of Physiology, Cornell University, Ithaca, NY 14853.

The sheep uses panting as its primary mode of evaporative heat loss. The purposes of this study were 1) to partition respiratory evaporative heat loss (REHL) of exercise into that which is a consequence of the increase in ventilation ($\dot{V}_E$) and that due to thermoregulation and 2) to assess the effects of stride frequency (SF) on respiration during exercise. Sheep were exercised on a treadmill at 30% of their maximal oxygen consumption for 40 min. Measurements were made of heat production (H_p) by indirect calorimetry, REHL, rectal temperature (T_r), and respiratory frequency (f). Tidal volume (V_T) and $\dot{V}_E$ were calculated from this data. Heat production reached steady state within one min of the onset of exercise. The increase in REHL as a result of the increased $\dot{V}_E$ associated with exercise represented 14 ± 2% of the increment in H_p. During exercise, REHL continued to increase in proportion to the increase in T_r. Respiratory frequency also continued to increase during the first 20-30 min of exercise. There was no evidence that f was synchronous with SF. Upon termination of exercise, f increased still further and V_T decreased suggesting the presence of thermal panting. However, REHL fell by an amount equal to the increment associated with the increased V of exercise. It was concluded that the REHL of panting was superimposed on the increased REHL of exercise in proportion to the internal heat load and that SF did not restrict development of thermally-induced REHL during exercise.

13.3

CORE TEMPERATURE PILL EVALUATION DURING EXERCISE/REST CYCLES. M.D. Quigley*, D. Toyota*, L. Blanchard*, M.A. Kolka and L.A. Stephenson. United States Army Research Institute of Environmental Medicine, Natick, MA 01760-5007.

This study examined how accurately a commercial (Human Technologies, Inc.) temperature pill (T_p) measured core temperature (T_c) compared to esophageal temperature (T_{es}) and rectal temperature (T_{re}) during exercise/rest cycles. Two hours after swallowing the pill, subjects (n=8) exercised on a cycle ergometer (T_a=29°C, T_{dp}= 11°C) for 40 min at 40% peak $\dot{V}O_2$, rested 15 min, then completed 3 cycles of 5 min of exercise at 80% peak $\dot{V}O_2$ and 5 min of rest. T_p, T_{es} and T_{re} were recorded every 30 seconds. When comparing mean response times (time in min for T_{es}, T_p or T_{re} to detect T_c Δ of 0.1°C) during exercise/rest cycles, differences ($p \leq 0.01$;n=6) were found between T_{es} (2.4±1.2), T_p (5.0±2.3) and T_{re} (6.7±3.3). Hence, T_{es} responded faster than T_p or T_{re}; and T_p responded faster than T_{re}. When comparing T_c during all exercise/rest cycles, the change in T_{es} was greater than in T_p or T_{re} ($p \leq 0.01$;n=6). During both rest and moderate exercise, T_{es} and T_p were lower ($p \leq 0.01$) than T_{re}. The peak temperatures measured during the experiment were not different among the three indices (p=0.61) when compared by one-way ANOVA with repeated measures. In this study, T_p responded more like T_{es} than T_{re}. Overall, T_{es} tracked changes in T_c better than either T_p or T_{re}. Pill mobility may affect interpretation of T_p data. (Funded in part by the P^2NBC^2 program)

13.4

OESOPHAGEAL AND RECTAL TEMPERATURE DURING UPPER BODY EXERCISE AT SIMILAR RELATIVE AND ABSOLUTE EXERCISE INTENSITIES. Elizabeth M. Gass* and Greg C. Gass. Faculty of Health Sciences, The University of Sydney, Australia, 2006.

This study using a model of interrupted (paraplegic) and uninterrupted (able bodied) neural supply has investigated the relationship between oesophageal (Toes) and rectal (Trec) temperatures, during upper body exercise. 5 paraplegics (T8 - T12) (P) and 5 able bodied arm crankers (AC) after giving consent completed standard anthropometry and an incremental test to exhaustion. Heart rate (HR), oxygen uptake ($\dot{V}O2$) and related variables were measured throughout exercise (Ex). 3-5 days later each subject after inserting temperature probes (AD590) into the oesophagus and rectum, underwent a 15 min rest followed by 35 min of Ex at 60 - 70% $\dot{V}O2$ max/peak. Throughout rest and Ex Toes and Trec were recorded. Data were analyzed by t-tests ($p < 0.05$). There was no significant difference in the Wt of the groups, however the P group was significantly older. The $\dot{V}O2$ max/peak for the P and AC groups was 2.61 ± 0.20 and 2.61 ± 0.24 l/min respectively and no significant differences in HR and $\dot{V}E$ were observed. No significant differences in resting Trec and Toes were found for the P group, but in the AC group, the Toes (36.8 ± 0.21°C) was significantly lower than Trec (37.2 ± 0.16°C). At the end of Ex Toes (38.16 ± 0.24°C) was significantly higher than Trec (37.66 ± 0.17°C) in (P) group. Although no significant difference in Toes and Trec was observed at the end of Ex for (AC) the Toes (37.50 ± 0.16°C) (AC) at the end of Ex was significantly lower than the Toes (38.16 ± 0.24°C) for (P) group. These results confirm the relationship of Trec and Toes in those with uninterrupted neural supply and in light of the results from the subjects with interrupted neural supply continue to question the contribution of muscle mass and (%) exercise intensity upon effector response.

13.5

DISSOCIATION OF RECTAL AND AURAL TEMPERATURES DURING LOWER-BODY EXERCISE. Graeme J. Maw* & Nigel A.S. Taylor* (SPON: S.H. Boutcher). Univ. of Wollongong, NSW 2500, Australia.

This study compared oesophageal (T_{oe}), rectal (T_{re}) and aural (T_{au}) temperatures in 6 healthy males at rest and during cycle ergometry (150 W) in thermoneutral (TN: 24°C, RH=40%), cold (CO: 13°C, RH=40%) and hot (HO: 36°C, RH=40%) environments. Subjects were monitored at rest in TN for 30 mins, and later during 30 mins cycling in TN, followed by 30 mins cycling in either CO or HO. At rest, T_{oe} (37.48±0.30°C) and T_{re} (37.46±0.26°C) were within 0.10°C in all cases, and exceeded T_{au} (36.86±0.35°C) by 0.60°C. During the first 20 mins of exercise in TN, T_{oe}, T_{re} and T_{au} rose in parallel by 0.40°C. From 20 to 30 mins, T_{oe} and T_{au} plateaued, while T_{re} rose a further 0.15°C. Continued exercise in CO caused T_{oe} and T_{au} to rise a further 0.15° and 0.20°C respectively, while T_{re} rose by 0.30°C. When exercise continued in HO, T_{oe}, T_{re} and T_{au} rose in parallel by 0.60°C without achieving equilibrium. During lower-body exercise in TN and CO, T_{re} may not accurately reflect central temperature changes measured elsewhere, becoming disproportionately elevated perhaps due to local blood flow from active muscle. T_{au} approximates changes in T_{oe}. Fluctuations in T_{oe}, attributed to increased ventilation and saliva, may make a fully insulated aural thermometer a more practical measure of core temperature during lower-body exercise.

13.6

EXERTIONAL HEAT EXHAUSTION IN CYCLISTS NOT CAUSED BY ENDOTOXEMIA Geoffrey E. Moore, M. E. Blair Holbein*, James Greiner*, James P. Knochel Presbyterian Hospital, Dallas, Texas, 75231

Endotoxemia (blood-borne bacterial lipid A) occurs after intestinal ischemia, triggers cytokines, and causes shock. At rest, normal endotoxin titer ranges from <10 to 100 pg/ml, but has been shown to average >300 pg/ml in exhausted athletes. Intestinal ischemia during exercise may allow endotoxemia, thereby causing exertional heat exhaustion. In west Texas, during August, 37 cyclists were studied at a 100 mile ride: 11 had heat exhaustion (HE) evidenced by tachycardia, symptomatic hypotension (dizziness), headache, rigors, nausea, vomiting, or severe cramps. 24/26 controls (C) tested pre and post had only asymptomatic hypotension or minor cramps; 2/26 C had HE. Blood was tested for hemoglobin (HB), sodium (NA), creatine kinase (CK), creatinine (CR), and uric acid (UR). Endotoxin titer (ETX) was measured by Limulus chromogenic assay (sensitivity ≈ 60 pg/ml). In C-pre, ETX was at threshold sensitivity in 2/26, but undetectable in 24/26. In C-post, ETX was 150 pg/ml in 1/26, at threshold in 2/26, but undetectable in 21/26 and the 2/26 C with HE. In HE, ETX was 330 pg/ml in 1/11, at threshold in 1/11, and undetectable in 9/11. Blood tests revealed typical changes of exercise in the heat, and similarity between C-post and HE. Data show mean±SEM; comparison by paired T-test for C-pre vs C-post (* $p < .05$), grouped T-test for C-post vs HE (‡ $p < .05$).

	HB g/dl	NA mEq/L	CK IU/L	CR mg/dl	UR mg/dl
C-pre	15.0±0.2	143±0.3	154± 34	1.5±0.04	5.4±0.3
C-post	15.1±0.2	142±0.6	561±191*	1.6±0.05*	6.3±0.3*
HE	14.3±0.5	138±2.0‡	195± 26	1.6±0.13	7.5±0.9

We conclude that endotoxemia (>100 pg/ml) occurs in asymptomatic cyclists, and that heat exhaustion occurs independently of endotoxemia. Endotoxemia may complicate, but does not cause exertional heat exhaustion in cyclists.

13.7

ACCUMULATION OF STRESS PROTEIN 72i IN FETUSES OF TRAINED PREGNANT RATS. M.F. Mottola, K. McKenzie*, C. Schachter, J. Mezzapelli*, J. VanHeest and R.M. Tanguay*. Univ. of Western Ont., London, Canada N6A 3K7 & CHUL Ste-Foy, P.O. Canada, G1V 4G2

The purpose was to determine if maternal exercise (60-70% VO_{2max}) induced a fetal heat shock response, represented by the accumulation of inducible isoform shock protein, SP72i, in trained rats. The accumulation of SP72i (R.M. Tanguay) was assessed in fetal brain, heart, kidney, hind limb and placenta of trained animals on day 20 of pregnancy (term=21 days). The exercise protocol consisted of treadmill running at 30 m/min on a 10° incline, 60 min/day, 5 days/week for 4 weeks prior to pregnancy and then continued throughout gestation up to and including day 18. After probing the above fetal tissues on day 20 of gestation with SP72i antibody, no significant differences were found for fetal heart, hind limb or placenta between trained animals and sedentary controls. SP72i was not detected in fetal kidney or brain in the trained or sedentary groups. Although heat shock response was not detected in the fetuses of the trained animals, fetal body weight and placental weights were significantly less than ($p<0.05$) sedentary controls, suggesting factors other than temperature may affect fetal growth. Support- NSERC Canada #0003669 & U.W.O.

13.8

CORONARY BLOOD FLOW IS NOT COMPROMISED BY SEVERE HYPERTHERMIA IN RATS. K.E. Anderson, R.J. Tomanek, and C.V. Gisolfi. Univ. of Iowa, Iowa City, IA 52242.

Selective loss of compensatory mesenteric vasoconstriction may trigger the cascade of events that characterizes heat stroke (Kregel, et al. J. Appl. Physiol. 64:2588, 1988). The purpose of this study was to determine the effects of elevating core temperature (T_c) above the LD_{50} (40.4°C) for survival on coronary blood flow (CBF) in rats exposed to an ambient temperature of 40°C. Radioactive microspheres 15 microns in diameter (Sn^{113}, Nb^{95}, Sc^{46}, Sr^{85}) were injected into the left ventricle of anesthetized Sprague Dawley male rats (300 - 350 g) at T_c approximating 37.0, 39.5, 41.0, and 42.5°C. Heart rate increased to 600 bpm and was highly correlated with T_c ($y = 0.02x + 30$, $r = 0.92$, $P = 0.0001$). Regression analysis for data falling within 95% confidence limits revealed strong positive correlations between CBF and T_c ($y = 38x - 1500$, $r = 0.66$, $P = 0.004$) and mean arterial pressure (MAP) and T_c ($y = 5.08x-115.6$, $r = 0.66$, $P = 0.001$). Caudal artery blood flow increased with heating, while renal blood flow fell throughout the heating period. Mesenteric artery blood flow decreased before increasing slightly at high T_c's. We conclude that under conditions of severe hyperthermia, CBF is maintained. This suggests that the precipitous fall in MAP during the prodromal period of heat stroke is not attributable to myocardial ischemia and cardiac failure. Supported by NIH Grants HL38959, HL14338 and HL32295.

13.9

SYMPATHO-ADRENAL RESPONSES TO EXERCISE-HEAT STRESS

C.M.Maresh, L.E.Armstrong, J.Hoffman*, C.Gabaree*, L.E.Ahlquist*, M.Bergeron*, J.Castellani*, R. Kenefick* and A.Ward*. U. of Connecticut, Storrs, CT 06269 & UMASS Med. Ctr., Worcester, MA 01655

Plasma norepinephrine (NE), epinephrine (EP), cortisol (CORT) and lactate (LA) were measured in 10 men (21±3 yr, 57±5 ml·min^{-1}·kg^{-1} $\dot{V}O_2$ max) before (PRE) and after (IP) 4 exercise-heat sessions (90 min, 5.6 km·h^{-1}, 5% grade; 33°C, 55% rh). These 4 sessions involved combinations of PRE hydration status [euhydrated (EU) or hypohydrated (HY, -3.8 ±0.7% body wt)] and water intake during exercise [ad libitum (W) or no water (NW)]. Exercise intensity (21% $\dot{V}O_2$ max) was similar across the 4 sessions. Plasma EP, CORT and LA were unchanged, IP vs PRE, but IP CORT during HY+NW (645±200 nmol·L^{-1}) was greater ($p<0.05$) than corresponding EU+W and EU+NW measures. Plasma NE increased ($p<0.05$) at IP, vs PRE, during EU+W (294 ±96 vs 129±54 nmol·L^{-1}), HY+NW (536±158 vs 204±85 nmol·L^{-1}), and HY+W (345±124 vs 175±28 nmol·L^{-1}). The NE value at IP during HY+NW was greater ($p<0.05$) than corresponding EU+NW, EU+W, and HY+W measures. Thus, plasma NE was sensitive to this prolonged exercise-heat stress, during moderate PRE hypohydration, and water deprivation during exercise.

13.10

STRENUOUS EXERCISE IN MILD AND HOT ENVIRONMENTS: METABOLIC, CARDIORESPIRATORY, AND THERMAL COMPARISONS.

L.E. Armstrong, C.M. Maresh, C.Gabaree*, J.Hoffman*, M.Whittlesey*, M.Bergeron*, A.Pasqualicchio†. Human Performance Laboratory, University of Connecticut, Storrs CT 06269-1110.

Few studies have compared physiologic responses in mild (M) and hot (H) environments, during strenuous exercise. Seven unacclimatized, highly-trained males (87 km run·wk^{-1}, 69.8 ml·kg·min^{-1} $\dot{V}O_2$max, 21 yr) ran in two environments (M: 23°C and H: 38°C; 7 days apart) at two treadmill speeds (S1: 240 m·min^{-1}, 68% $\dot{V}O_2$max; S2: 270 m·min^{-1}, 77% $\dot{V}O_2$max; 10 min each). ANOVA (H versus M at S2) indicated: **increased** ($p<0.025$) plasma lactate (LA, 4.8 vs 3.5 mmol·l^{-1}), mean skin (37.0 vs 33.4°C) and tympanic (38.4 vs 36.0°C) temperatures, respiratory exchange ratio (R, 1.22 vs 0.99), heart rate (189 vs 176 beats·min^{-1}), and rating of perceived exertion (15 vs 13); as well as **decreased** ($p<0.01$) steady-state oxygen consumption (45.5 vs 54.1 ml·kg·min^{-1}). However, **similar** values were observed during M and H, for plasma volume change, plasma glucose, and respiratory gases ($\dot{V}_e$, $\dot{V}CO_2$, and $\dot{V}e/\dot{V}CO_2$). These data suggested that strenuous exercise in H (versus M), in addition to greater thermal strain, resulted in increased anaerobic metabolism (increased R and LA >4 mmol·l^{-1}; decreased $\dot{V}O_2$).

13.11

EFFECT OF WATER TEMPERATURE ON THE SWIMMING ENERGETICS OF SEA LIONS

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In the wild, California sea lions (Zalophus californianus) occur in water temperatures (T_w) ranging from 8° to 30°C. To determine the effect of T_w on swimming metabolic rate, we swam four subadult sea lions (mean mass 33 kg) in a water channel at 20°, 12°, and 5°C. Oxygen consumption ($\dot{M}O_2$) was measured at rest and at three workloads. Core body temperature (T_b) was monitored by radio telemetry. The results showed a 38% increase in resting $\dot{M}O_2$ with a decrease in water temperature ($\dot{M}O_{2rest}$ = 6.33 ± 1.05 ml O_2/kg/min at 20°C; 8.73 ± 0.52 ml O_2/kg/min at 5°C). However, there was no significant difference in swimming $\dot{M}O_2$ up to a maximum of 30 ml O_2/kg/min at the three T_w. T_b was maintained between 36.0° to 38.5°C at all T_w and workloads. The results show that the energetic cost of swimming in sea lions is independent of T_w ranging from 5° to 30°C. These results have important implications for pinniped energetics and thermoregulation at sea.

13.12

REACTION TIMES AND EVOKED POTENTIALS DURING MODERATE INTERNAL AND EXTERNAL COOLING.

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The mechanisms underlying the effect of brief or prolonged central and peripheral cooling on reaction time and central nervous system conduction velocity are not well understood. In the present study, simple reaction time (RT), somatosensory evoked potentials (SEP), visual evoked potentials (VEP), auditory evoked potentials (AEP), rectal and skin temperatures (Tr, Ts), and perceived temperature or discomfort (Tp) were monitored in eleven male subjects (age25.3±2.7) during internal cooling by ice slurry ingestion (IC) or external cooling by exposure to 7°C air (EC). A decrease in VEP latency indicating increased central conduction velocity and faster reaction times was observed in the EC condition. Tr was unchanged, but both Ts and Tp suggested considerable discomfort. In contrast, during the IC condition when Tr decreased significantly, RTs were unchanged and Ts and Tp indicated little discomfort. AEPs and SEPs both increased in latency.

	7° air exposure			Ice slurry ingestion		
* ($p\leq0.05$)	Control	30 min.	90 min.	Control	30 min.	90 min.
Tr	37.52	37.38	37.15	37.6	36.7*	36.8*
Ts	33.81	29.81*	28.91*	34.12	33.77*	33.99
TP	95.3	68.4*	54.3*	95.1	94.2	91.3
RT	0.30	0.26*	0.30	0.30	0.31	0.30
AEP (V)	5.95	6.01	5.92	5.89	6.07	6.04*
SEP (P37)	5.98	6.01	5.92	5.89	6.07	6.05*
VEP (P100)	103.78	98.78*	99.38	101.73	103.89	100.56

In summary, these results suggest that the peripheral discomfort associated with EC causes central nervous system arousal resulting in increased conduction speed in visual pathways which reduce RT. Decreased conduction velocities resulting from central cooling may offset this effect. IC, in contrast, results in little or no arousal, and thus no reduction in reaction time, but significant reductions in nerve conduction velocity. The differing effects of IC and EC should be considered when applying artificial cooling to maintain or improve human performance. Funded in part by the Naval Medical Research and Development Command Grant # N0014-88-K-0582.

ENDOCRINE PHYSIOLOGY

14.1

THE RELATIONSHIP BETWEEN TWO PHYSICAL ACTIVITY RECALL TOOLS AND BONE MINERAL DENSITY AT AXIAL AND APPENDICULAR SITES IN FEMALES 12-22 YEARS.

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The purpose of this study was to describe the relationship between bone mineral density (BMD) and estimated caloric expenditure (KCAL-E) in young (12-22yrs), healthy eumenorrheic females. BMD measurement sites included: lumbar spine, femoral neck, and total body (dual-energy radiography), and mid-radius (single photon absorptiometry). KCAL-E was obtained from the Seven Day Physical Activity Recall (7 PAR) and the Paffenbarger PAR (P PAR). KCAL-E were also expressed relative to body weight (kg). Pearson correlation coefficients are reported:

SITE	7 PAR	7 PAR/kg	P PAR	P PAR/kg
Lumbar	.53**	.33*	.49**	.43**
Fem. neck	.47**	.27*	.48**	.42**
TB	.53**	.24*	.42**	.34**
Radius	.23*	.10	.32**	.30*

* $p < .05$ ** $p < .01$

It is concluded that significant relationships exist between KCAL-E tools and BMD at various sites in young females.

14.2

THE EFFECTS OF MUSCLE ACTION AND SHORT-TERM DETRAINING ON HORMONAL RESPONSES TO EXERCISE.

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To examine the effects of the mode of muscle action and detraining on serum growth hormone (GH), testosterone (T), free testosterone (FT), sex-hormone binding globulin (SHBG) and cortisol (C) concentrations in the venous blood, 32 male subjects (n=8 in each group) who had just completed resistance training (using the same leg exercises but different muscle actions) for 19 weeks were either a member of group CON/ECC (performed concentric [con] and eccentric [ecc] muscle actions in training), group CON/CON (performed double con actions), group CON (performed only con muscle actions in training), or a CONTROL group (performed no training). Each performed 3 sets of 30 isokinetic con knee actions on one test day and 3 sets of 30 isokinetic ecc knee actions on another test day 48 hr later both after training and again after 4 weeks of no training. Blood samples were obtained before and after each exercise test. No significant differences were observed for T, FT, SHBG or C for the responses to con and ecc tests or with detraining. Significant ($p<0.05$) post-exercise GH concentrations were: con exercise less than ecc exercise after training and con exercise greater than ecc exercise with detraining for the CON/ECC group; con exercise greater than ecc exercise after training and no difference between con and ecc exercise with detraining for the CON/CON group; con exercise greater than ecc exercise after training and no differences with detraining for the CON group; no significant differences were observed between con and ecc exercise for the CONTROL group. These data indicate that serum GH is the most sensitive to the mode of muscle action and differential responses with exercise after short-term detraining.

14.3

ENDOCRINE REACTIONS TO A MARATHON RACE AT HIGH ALTITUDE.
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Plasma hormone concentrations were measured in 17 male residents before and after a marathon race at approx. 2700 m altitude (barometric pressure 550 torr) under moderate climatic conditions. Control values for aldosterone (98.4 + 34.1 pg/ml, mean and SD) and atrial natriuretic peptide (83.3 + 24.7 pg/ml) were lower and higher, respectively, than in subjects from sea level, whereas antidiuretic hormone (0.7 + 0.4 pg/ml) and cortisol (98.4 + 34.1 µg/dl) did not differ. After exercise (immediately, 1 h and 24 h) aldosterone (+310.6 + 187.6, +164.2 + 201.7, +57.0 + 80.6 pg/ml), antidiuretic hormone (+4.1 + 3.3, +2.7 + 2.3, +0.4 + 0.6 pg/ml) and cortisol (+42.2 + 19.0, +29.5 + 25.2, -4.2 + 3.5 µg/dl) increased markedly. Atrial natriuretic peptide, however, decreased (-13.3 + 20.6, -34.6 + 14.9, -33.1 + 11.3 pg/ml). Plasma volume (calculated from changes in hemoglobin concentration and hematocrit value) increased by 11.4 + 10.8 % 24 h after exercise. Thus, volume conserving endocrine reactions after exercise are not attenuated at altitude in well-adapted subjects.

14.4

INDUCED ALKALOSIS SUPPRESSES THE GROWTH HORMONE RESPONSE TO ACUTE, HIGH-INTENSITY CYCLE EXERCISE.
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To investigate the effect of acid-base balance on serum growth hormone (GH) concentration after an acute, high-intensity, anaerobic exercise bout, ten normally-active men (age, 24.6±4.9 yrs) participated in a randomized, double-blinded, counterbalanced experiment with crossover design. Each subject reported in a fasted state at the same time of day for two experimental sessions separated by one week. For each session, subjects were administered a decaffeinated tea solution containing either the supplement (S) (0.3g $NaHCO_3 \cdot kg\ bw^{-1}$) or placebo (P) (0.04g $NaCl \cdot kg\ bw^{-1}$) over a 45-min ingestion period. Venous blood samples were obtained before (baseline, [BL]) and 75 min after (PRE-EX) the ingestion period, as well as at 0, 5, 10, 15, 20, and 30 min post-exercise. The exercise task immediately followed the PRE-EX blood draw, and consisted of 90 sec of maximal-effort cycle ergometry against an opposing force of 0.49 N (0.05kg) per kg of body weight. There were no differences between the S and P conditions in mean or peak power output or total work. Mean (±SE) blood pH and serum [GH] results were (* p<0.05 vs. corresponding BL within condition; † p<0.05 vs. corresponding P timepoint):

				POST-EXERCISE (min)					
	CONDIT	BL	PRE-EX	0	5	10	15	20	30
pH	P	7.36	7.36	7.09*	7.07*	7.09*	7.12*	7.17*	7.25*
		(0.01)	(0.01)	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
	S	7.37	7.43*†	7.16*†	7.14*†	7.18*†	7.22*†	7.27*†	7.35†
		(0.01)	(0.01)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
GH	P	0.8	0.2	0.3	1.1	4.1*	8.2*	11.4*	12.5*
($\mu g \cdot L^{-1}$)		(1.3)	(0.4)	(0.5)	(0.7)	(2.1)	(4.1)	(5.8)	(7.9)
	S	1.2	0.4	0.4	0.5	1.3	3.3†	5.2*†	7.3*†
		(2.5)	(0.5)	(0.5)	(0.5)	(0.9)	(2.4)	(3.9)	(4.8)

These data indicate that an increased blood hydrogen ion concentration is partly responsible for the serum growth hormone response to acute, high-intensity anaerobic exercise.

14.5

REPRODUCTIVE FUNCTION IN MALE RUNNERS.
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The purpose of this study was to evaluate the effects of volume of endurance training on reproductive function in male runners. Analyses of reproductive hormones and semen quality were performed in 11 high mileage runners (HR) (67.5±2.8 mi/wk), 9 moderate mileage runners (MR) (33.9±2.3 mi/wk) and 10 sedentary controls (C) of similar age (28.3±1.5 yr). Levels of total testosterone (TT), free testosterone (FT), luteinizing hormone (LH), follicle-stimulating hormone (FSH) and prolactin (PRL) were measured during a 1hr period of serial blood sampling (q20 min). Urinary excretion of 24 hr-LH (uLH) was determined on two separate days. Semen exams (2-5) for sperm count, density, motility and morphology and sperm penetration of standard cervical mucus (Penetrak) were performed. Levels of TT and FT were significantly lower in HR (15.3±1.3 nmol/l and 60.2±5.1 pmol/l) compared to MR (21.4±1.6 nmol/l and 86.0±6.1 pmol/l) and C (19.5±0.9 nmol/l and 75.9±3.6 pmol/l). No differences ($p>0.05$) were found in uLH, LH, FSH, and PRL among the three groups. Total motile sperm count and density were lower ($p<0.05$) in HR than C. A decreased ($p<0.006$) sperm motility and a higher ($p<0.004$) volume of immature sperm and round cells were observed in HR compared to MR and C. An indicator of fertility, sperm penetration of standard cervical mucus, was also decreased ($p<0.024$) in HR compared to C. These findings suggest that a high volume of endurance running results in decreased gonadal steroids and alterations in semen quality that may negatively affect fertility capacity.

14.6

FEMALE SEX HORMONES AND ATHLETIC PERFORMANCE.
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Fourteen cyclic ovulatory, elite athletes had $\dot{V}O_2max$ tested during the follicular (F) and luteal (L) phases of a normal menstrual cycle, and were then randomized to one of two equal treatment (RX) groups: pill (PILL: 27.1 ± 1.6 yr, (mean ± SE); Ht = 168.5 ± 1.9 cm; Wt = 60.2 ± 1.7 kg) or placebo (PLA: 28.3 ± 1.6 yr, Ht = 168.6 ± 2.0 cm; Wt = 60.0 ± 3.5 kg). The third test was done between days 14-17 on PILL (Synphasic, a low-dose triphasic oral contraceptive agent) or PLA, in the second month on RX. To confirm the cycle phase, pre-exercise estradiol and progesterone levels were obtained. All 14 women showed hormonal evidence of normal ovulation. Relative $\dot{V}O_2max$ decreased slightly in both groups during the luteal phase, and there was a significant differential response to RX ($p = 0.018$) between the subjects on PILL (F: 54.73 ± 1.7; L: 53.74 ± 1.2; RX: 52.04 ± 1.0 ml/kg/min) as compared to the women on PLA (F: 53.01 ± 1.1; L: 51.89 ± 1.3; RX: 53.78 ± 1.7 ml/kg/min). Since at the time of the third test, women in the PLA group had various endogenous hormone levels, concomitant hormonal analysis was essential to accurately interpret any subtle exercise changes. The data suggest that the female sex hormones, both endogenous and exogenous, may have an adverse effect on aerobic performance at the elite level.

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14.7

EFFECTS OF SLEEP DEPRIVATION AND PHYSICAL ACTIVITY ON THYROID HORMONES DURING MILITARY MANEUVERS IN THE ARCTIC.
A.C. Hackney, J.A. Hodgdon, and R. Hesslink, Jr. Naval Health Research Center, San Diego, CA 92152.

Military field maneuvers involving sleep deprivation (SLP) and high physical activity (PA) levels in thermoneutral environments cause transient increases, followed by declines, in thyroid hormones. However, brief cold exposure is associated with elevated levels of thyroid hormones. We examined the effects of SLP and PA level during military field maneuvers in the arctic on thyroid hormone levels. Norwegian soldiers (n=35) were divided into 4 groups having low (2 h) or high (6 h) levels of SLP, and low or high PA requirements during maneuvers. Maneuvers were 3 days of simulated combat scenarios during winter. Day 1 consisted of 24 h without sleep. Sleep was then provided at 12 h intervals thereafter. Blood samples were taken at 0 h, 24 h, 48 h, 72 h, and at 24 h and 48 h of recovery (R). Hormonal analysis consisted of total (t) T4, free (f) T4, tT3, fT3, and TSH. Main effects for time (i.e., days) were observed for all hormones ($p<0.001$). TSH declined throughout the maneuvers, as did fT3 (generally). tT4, fT4, and tT3 increased in the first 24 h, then declined daily through R-24 h. By R-48 h tT4, fT4 and TSH showed trends towards returning to 0 h levels; however, fT3 was still reduced and tT3 levels were variable. Interaction effects for SLP and PA groupings were found for the tT4 and fT4 responses only; however, these effects were very slight. The present findings suggest that possibly the arctic cold exposure slightly altered the thyroid hormone responses (i.e., fT3, TSH) from those previously found during military field maneuvers. Interestingly, the amount of SLP and PA levels during the 3 day period appears to be only minimal in impact upon the thyroid hormone responses.

14.8

EFFECTS OF SLEEP DEPRIVATION AND PHYSICAL ACTIVITY ON BLOOD TESTOSTERONE - CORTISOL LEVELS DURING MILITARY MANEUVERS IN THE ARCTIC.
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Sleep deprivation (SLP) and high physical activity (PA) levels in thermoneutral environments are associated with reductions in blood testosterone (T) and elevations in cortisol (C) levels. It is unclear whether or not the effect of these stressors are additive, or are modified by cold exposure. This study examined the effects of SLP and PA level during military field maneuvers in the arctic on T and C levels. Norwegian soldiers (n=35) were divided into 4 groups having low (2 h) or high (6 h) levels of SLP, and low or high PA requirements during maneuvers. Maneuvers were 3 days of simulated combat scenarios during winter. Day 1 consisted of 24 h without sleep. Sleep was then provided at 12 h intervals thereafter. Blood samples were taken at 0 h, 24 h, 48 h, 72 h, and at 24 h and 48 h of recovery (R). A significant ($p<0.001$) variation in the level of each hormone across time (i.e., days) was found. Also, significant ($p<0.05$) PA by time interactions were found for both T and C. No significant ($p>0.05$) SLP by time interactions were noted. T was reduced from 0 h in both PA groups at 24 - 72 h and R-24 h. However, at 48 h T in the high PA group was lower than in the low PA group ($p<0.01$). In the low PA group C declined ($p<0.01$) throughout the maneuvers such that the 72 h, R-24 h, and R-48 h levels were less than 0 h. Conversely C in the high PA group was elevated at 48 h from the 0 h level, but then declined and was reduced at 72 h and R-24 h from the 0 h level. At R-48 h C began to increase for all groups (generally). T responses appear unaltered from those previously reported. C responses varied slightly from anticipated, however it is unclear if this is related to the cold exposure or other factors. These results provide no evidence for additive effects of SLP and PA level on the T and C response to arctic military maneuvers.

14.9

EXPOSURE TO 0° C AIR SUPPRESSES ACTH, B-ENDORPHIN AND CORTISOL DURING HIGH INTENSITY CYCLE ERGOMETRY.

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Exercise of sufficient intensity and duration is a potent stimulator of the hypothalamic-pituitary-adrenal (HPA) axis under euthermic conditions. The purpose of this study was to measure plasma ACTH, beta-endorphin (BE) and cortisol (Cort) concentrations during 60 min of cycle ergometry at two exercise intensities (60% and 80%) while exposed to (35° C) hot (H) or (0° C) cold (C) air. Active (n=15), but not endurance trained, men of average fitness (45 $mlO_2*kg^{-1}*min^{-1}$) participated in this double-blind randomized study. Serial venous blood samples were obtained via intra-venous (IV) catheter at euthermic rest, every 15 min during exercise in an environmental chamber and 15 min post exercise at euthermic rest. A 2 mg dose of naloxone (N) or equivalent dose of saline (S) was administered IV push, 15 min prior to exercise. This was followed by a N or S IV drip. The total dose of N administered was 0.1 $mg*kg^{-1}$. ACTH and BE concentrations were unchanged from rest during 60% exercise and cold/saline (CS), cold/naloxone (CN) or hot/saline (HS) conditions. The hot/naloxone (HN) condition at 60%, resulted in ACTH and BE nearly doubling compared to rest. Cort increased 50% at 60% intensity during HS and HN compared to CS and CN, which were decreased slightly from rest. Exercise at 80% intensity, did not change Cort from rest for CS, CN, HS *and HN. During HN,* ACTH and BE increased 300% above rest and HS conditions resulted in a 200% increase above rest. ACTH and BE were unchanged from baseline during CS and CN conditions. We conclude that exposure to cold air which does not result in lowered core body temperature, suppresses the HPA axis response to exercise at high intensity.

14.10

HORMONAL RESPONSES TO STRENGTH DETRAINING.

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Endocrine responses to chronic resistive exercise have been documented, but it is unclear if these effects are chronic or acute in nature. 13 strength-trained (3-6 $d \cdot wk^{-1}$, 3-5 sets of 5-12 reps of 80-95% of maximal weights for 5-7 exercises) men (age 24 y, mass 88 kg) were tested during normal training (pre) and 14 d after (post) the last exercise bout for maximal squat (SQ), bench press (BP), quadriceps isometric strength (MVC), a 12-h fasting blood sample, and a 2-h OGTT. No pre-to-post changes occurred in SQ (192 vs. 190 kg), BP (135 vs 133 kg), or MVC (977 vs. 905 N) ($P > .05$). Significant changes occurred in growth hormone (1.22 vs 1.88 $ng \cdot ml^{-1}$), cortisol (20.99 vs 16.44 $ng \cdot ml^{-1}$), testosterone (7.77 vs 9.28 $ng \cdot ml^{-1}$), testosterone to cortisol ratio (0.39 vs 0.62), and the insulin sensitivity index (5.05 vs 4.15) from the OGTT. The enzyme serum creatine kinase also decreased (854 vs 151 $IU \cdot l^{-1}$) (all $P < .05$). These data suggest that the hormonal milieu during detraining may be conducive to an enhanced anabolic process and that short-term detraining does not necessarily impair performance in muscular strength.

Supported by a Research Grant from East Carolina University

14.11

EXERCISE TRAINING AND CLENBUTEROL REDUCE THE INSULIN RESISTANCE OF OBESE ZUCKER RATS

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This study compared the effects of exercise training and chronic administration of the selective β_2-adrenergic agonist, clenbuterol, on whole body and skeletal muscle insulin resistance in obese (fa/fa) Zucker rats. Obese rats were randomly assigned to training, clenbuterol or sedentary control groups. Lean littermates served as a second control group. After 4-5 wk of treatment, an oral glucose tolerance test was performed, followed one wk later by hindlimb perfusion during which time the rates of glucose uptake and 3-O-methyl-D-glucose (3-OMG) transport were assessed in the presence of a submaximal (500 μU/ml) insulin concentration. Training resulted in a significant increase in citrate synthase and cytochrome oxidase activity in the recruited muscles (28-78%). Clenbuterol induced a large increase in muscle mass, but provoked a significant decrease in oxidative enzyme activity (34-55%) and β-adrenergic receptor density (61%). Both treatments increased whole body glucose tolerance and reduced the post-glucose insulin response. However, only exercise training improved hindlimb muscle glucose uptake (11.37±0.65, 8.73±0.77, and 8.27±0.41 μmol/g/h for trained, clenbuterol and sedentary control groups, respectively), and 3-OMG transport when expressed per gram of tissue. Clenbuterol treatment increased total hindlimb glucose uptake by increasing the quantity of muscle. These results indicate that the two interventions attenuated the insulin resistant condition in obese Zucker rats through different mechanisms.

14.12

EXERCISE IN TYPE II (NON-INSULIN DEPENDENT) DIABETIC PATIENTS.

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This study was performed to investigate the acute and chronic effects of exercise in Type II diabetic patients. 21 patients 2 h. after a standard breakfast, exercised submaximally ana bicycle ergometer (Monark 814E) for 30 min.. The exercise program was designed for 3 days in a week for 8 weeks. In all the patients postprandial blood glucose, serum insulin, serum cortisol, and serum growth hormone levels, and catecholamin levels in the urine have been measured before the exercise, immediately after the exercise and at the end of the 8 weeks exercise program. In order to observe the late effects of exercise, we ceased the exercise program for 4 weeks and after this period we measured the same parameters, again.

There was a pronounced decrease in the levels of postprandial blood glucose and serum insulin levels immediately after the exercise session and the completion of the 8 weeks exercise program. But there wasn't any significant difference between these results. After 4 weeks of non-exercise period there was a significant increase in the blood glucose and serum insulin levels. Also, no significant difference was observed in the serum cortisol and serum growth hormone levels and urine catecholamin levels. In conclusion, we recommended that type II diabetic patients should exercise submaximally and regularly in order to keep their blood glucose and serum insulin levels in a tolerable level.

ADAPTATION

15.1

EFFECTS OF INTENSIVE CONTINUOUS VERSUS INTERVAL TRAINING ON ENDURANCE CAPACITY AND SKELETAL MUSCLE ENZYMES.

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Trained runners performed supervised training 3 times a wk for 6 wks, group CT (n=12) with continuous running for 30 min at 92% of HRmax per training bout, and group IT (n=12) with six 4-min intervals at 95% HRmax separated by 2-min periods of rest. VO_{2max} increased 7% in both groups (54.7±3.2 to 58.6±2.9 ml O_2/min/kg; mean±SD; $p<0.0001$). Mean endurance capacity, i.e. time to exhaustion at 85% of pretraining VO_{2max}, increased 27% more in CT (from 35.5±9.3 to 69.0±15.1 min; $p<0.0001$) than in IT (from 36.4±7.6 to 60.9±9.4 min; $p<0.0001$), (ΔCT vs ΔIT; $p<0.05$). VO_2 and RQ during the endurance tests were not significantly altered. Max citrate synthase (CS) activity in m. vastus lateralis was 34.4±7.3 pre- vs 37.7±7.8 posttraining in CT (ns), and 35.3±7.6 vs 36.3±8.1 μmol/g dry wt/min in IT (ns). β-hydroxyacyl-coenzym A dehydrogenase (HAD) values were 32.3± 6.6 vs 27.8±5.6 in CT; ($p<0.01$), and 30.6±6.3 vs 30.5±8.5 μmol/g dry wt/min in IT. Muscle glycogen was unaltered. We conclude that intensive continuous training is a more potent stimulus for endurance capacity than interval training which, however, also has a significant effect. The improved performance is not related to metabolic indicators such as RQ, CS or HAD activities.

Supported by Team Danmark.

15.2

PLASMA β-ENDORPHIN IMMUNOREACTIVITY FOLLOWING RESISTANCE EXERCISE

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Previous research investigating the response of plasma β-endorphin (β-EP) to resistance exercise has resulted in equivocal findings. To examine the effects of an acute bout of resistance exercise on β-EP immunoreactivity, six resistance trained athletes (age (yr) = 20.5 ± 0.4 (SE); height (cm) = 189.6 ± 4.7; weight (kg) = 106.4 ± 9.6) participated in a 3 set series of 8 repetitions at 80% of 1 repetition maximum (1-RM) for each of the following free weight exercises: 1) bench press 2) incline press 3) standing curls 4) flat bench dumbbell raises, and 5) leg curls. Three minutes of rest were allowed between exercises and completion of the exercises required approximately 45 minutes. Blood was sampled from the group by venipuncture, both prior to and following the exercise bout and β-EP was determined by radioimmunoassay. A student's t-test for paired observations indicated that plasma levels of β-EP following exercise (18.0 ± 3.4 (SE) pg β-EP ml^{-1}) were not significantly changed from pre-exercise (control) levels (19.6 ± 2.4 pg β-EP ml^{-1}), although there was considerable inter-individual variability. Our results support previous research which has reported no significant increase in β-EP levels following resistance exercise, as well as reported findings of considerable variability in the β-EP response to exercise.

15.3

PHYSICAL ACTIVITY ENHANCES SPATIAL LEARNING PERFORMANCE WITH AN ASSOCIATED ALTERATION IN HIPPOCAMPAL PROTEIN KINASE C ACTIVITY IN C57 AND DBA MICE. D.E. Fordyce* and J.M. Wehner*. Institute for Behavioral Genetics (SPON: R.P.Farrar). The University of Colorado at Boulder, Boulder, CO. 80309-0447

The effects of physical activity on spatial learning performance and associated hippocampal functioning were examined in C57BL/6 and DBA/2 (lbg) mice. Previously, we observed a marked enhancement in spatial learning performance and associated alterations in hippocampal cholinergic function of rats exposed to physical activity (Fordyce and Farrar, 1991, Beh. Brain Res.46:123-133). Because of genetic analyses afforded by using inbred strains of mice, it was of interest to examine if this physical activity effect could be achieved in two strains of mice differing in learning performance (Wehner et al., 1987, Brain Res. 523:181-187). C57 and DBA mice (3 months of age) were subjected to an eight week physical activity protocol consisting of moderate pace (0.4 mph) treadmill running 5 days/week and 60 min/day. Mice were then tested on the Morris water task for 6 days followed by the place learning-set task for 12 days (8 trials/day with each task). Hippocampal protein kinase C activity was measured in cytosolic, loosely-bound and membrane-bound homogenate fractions. Mice subjected to the physical activity protocol were compared to age-matched sedentary controls from the same set of litters. Physical activity enhanced performance on both the Morris and place learning-set task probe trials ($p<.02$). DBA mice, which characteristically perform poorly in comparison to C57 mice, were enhanced to perform similarly to C57 mice. These alterations in performance were accompanied by alterations in membrane-bound protein kinase C activity ($p<.05$). The data from this study, therefore, indicate that the protein kinase C second messenger system, as well as cholinergic function, in the hippocampus may be involved in the physical activity-induced enhancement of spatial learning performance.

Supported by NSF BNS-8820076 and NIH HD-07289 postdoctoral grants.

15.4

THE INTERACTION OF CREATINE DEPLETION AND ENDURANCE EXERCISE UPON AEROBIC CAPACITY OF MUSCLE B. Dorgan*, H.Park*, R.P.Farrar Dept. of Kinesiology, Univ. of Texas, Austin, TX.

Depletion of creatine by the feedings of ß guanidinopropionic acid (ßGPA) in the diet has been utilized to determine whether changes in the spatial and temporal buffering of the phosphorylation potential can induce changes in aerobic capacity of the muscle. F344 male rats were divided into two dietary groups, a pair-weighted group on laboratory rat chow and a ßGPA diet group. Exercise was implemented to exacerbate changes in the phosphorylation potential induced by creatine depletion. Two forms of endurance training were utilized: (1) steady-state endurance training of 30m/min, 60 min/day, and (2) high intensity interval training of up to 10 bouts of 2 min sprints at 60m./min. Following 12-15 weeks of this protocol the soleus (SOL) and plantaris (PLN) muscles were evaluated for changes in citrate synthase (CS) activity. ßGPA increased the CS activity by 24% and 40% in the PLN and SOL, respectively, of the sedentary rats. The steady-state training in the control diet group increased the CS activity by 50% in the PLN and 80% in the SOL, while the interaction with ßGPA induced 160% and 100% in the PLN and SOL muscles. In the interval trained rats the CS activity was same as the steady-state trained in the PLN, but lower in the SOL, demonstrating only a 40% increase over control values vs 100% in the steady-state SOL. The interaction of ßGPA and interval training induce the same increase in the PLN and SOL muscles as did the steady-state training ßGPA interaction. Contractile activity in the creatine depleted SOL is sufficient to induce large increases in CS activity, even though the load on the muscle at the high velocity runs is reduced, as evidenced by the CS activity of SOL of interval trained rats on control diet.

15.5

ALTERATIONS IN HUMAN SKELETAL MUSCLE ENERGY METABOLISM INDUCED BY 8 HOURS PER DAY OF LOW-FREQUENCY ELECTRICAL STIMULATION. R. Thériault*, Y. Gélinas*, G. Thériault, and J.-A. Simoneau. Physical Activity Sciences Laboratory, Laval University, Ste-Foy, Québec, Canada, G1K 7P4.

The purpose of the study was to verify the influence of chronic low-frequency electrical stimulation (LFES) on the energy metabolism of human skeletal muscle. LFES was delivered to the knee extensor muscles of 5 subjects at 8 Hz, 8 hours per day, 6 days/wk, with the use of a portable stimulator and adhesive electrodes (Respond II and Pals Plus, Medtronic). Vastus lateralis muscle samples were taken before, after 4 weeks, and after 8 weeks of LFES, and analyzed for enzyme activities of phosphofructokinase (PFK), citrate synthase (CS), cytochrome c oxidase (COX), and 3-hydroxyacyl CoA dehydrogenase (HADH). ANOVA revealed no significant change in PFK ($p>0.05$) after 4 or 8 weeks of LFES. On the other hand, CS, COX, and HADH activities increased significantly by 36% ($p<0.05$), 29% ($p<0.05$), and 21% ($p<0.05$) after 4 weeks, and by 23% ($p<0.05$), 36% ($p<0.05$), and 13% ($p<0.05$) after 8 weeks of LFES, respectively. Although chronic LFES has significantly altered the human skeletal muscle aerobic-oxidative metabolism, results of the present study suggest that human skeletal muscle has a limited capacity of adaptation in response to a chronic increase in contractile activity.

Supported by FRSQ, FCAR, Medtronic of Canada, & NSERC of Canada

15.6

PHYSICAL CONDITIONING CAN MODULATE ENDOTHELIUM-DEPENDENT VASORELAXATION IN RABBITS. Hsiun-ing Chen and Hsing-Tan Li*. Department of Physiology, Medical College, National Cheng-Kung University, Tainan, Taiwan 70101, Republic of China

To investigate whether exercise training can modulate the endothelium-dependent vasorelaxation or not, male New Zealand White rabbits were used for this study. They were divided into two groups, i.e., control (C) or training (T). Group T was trained by treadmill with running speed of 0.88 km/hr, 0° grade, 5 days/week for 8 weeks. The resting heart rate was lowered after exercise training ($p<0.05$). At the end of experiments, thoracic aorta and inferior vena cava, 5 mm in length for each, were excised and incubated in 15 mM Tris-HCl buffer (pH 7.4). After 30 min of incubation, the incubating buffer was discarded and replaced with fresh buffer for another 10 min. PGI_2 release from these vessels was then determined by radioimmunoassay of its stable metabolite, 6-keto-$PGF_{1\alpha}$. In addition, three vessel segments, i.e., thoracic aorta, pulmonary artery and common carotid artery (3 mm in length for each), were isolated and pre-contracted with 10^{-7}, $10^{-6}$and 10^{-6} M norepinephrine (NE), respectively. The vessel tension was measured by a force transducer. Basal release of endothelium-derived relaxing factor (EDRF) was measured by addition of hemoglobin. EDRF release was also stimulated by endothelium-dependent vasodilator, acetylcholine (ACh), in the presence of indomethacin (10^{-5} M). Dose-response relationship of ACh-induced vasorelaxation and NE-induced vasoconstriction was compared between control and trained groups. The results indicated that after exercise training, 1) PGI_2 released from thoracic aorta was increased; 2) PGI_2 released from thoracic aorta was significantly higher than that from inferior vena cava; 3) $[ACh]_{ED50}$ of thoracic aortae was reduced; 4) $[ACh]_{max}$ in thoracic aortae and pulmonary arteries were lowered; 5) $[NE]_{ED50}$ of the thoracic aorta was elevated; 6) there was no significant difference in basal release of EDRF and ACh-induced maximal relaxation of preconstricted vessel segments between control and trained rabbits. Our data suggest that exercise training may modulate endothelium-dependent vasodilatation.

15.7

SUPERIOR WORK PERFORMANCE IN LIFELONG TIBETAN RESIDENTS OF 4400m COMPARED WITH 3658m. L. Curran-Everett*, J.G. Zhuang*, T.S. Droma*, and L.G. Moore. Tibet Institute of Medical Sciences, Lhasa, Tibet, China, U. of Colorado, Denver CO 80217, and Cardiovascular Pulmonary Research Laboratory, U. of Colorado Health Sciences Center, Denver CO 80262.

Exercise performance is a measure of the integrated functioning of the O_2 transport system. Tibetan nomads live and work at some of the highest altitudes in the world. Their ability to exercise under these conditions may define the limits of human adaptation to hypoxia. We studied 20 male nomads born and raised at 4400m and 16 male lifelong residents of Lhasa (3658m), matched for age, height, and weight. All studies were performed in Lhasa. Standard test protocol and criteria were used for attaining $\dot{V}O_2$max on a Monark bicycle ergometer. Nomads compared with Lhasa residents had, at maximal effort, similar $\dot{V}O_2$ (48.5 ± 1.2 vs. 51.2 ± 1.3 ml/kg-min, p=ns), higher workload attained (211 ± 6 vs. 177 ± 7 watts, $p<0.01$), lower heart rate (176 ± 2 vs. 191 ± 3 bpm, $p<0.01$), lower ventilation (127.5 ± 4.6 vs. 149.1 ± 5.2 l/min BTPS, $p<0.01$), and similar SaO_2 (81.9 ± 1.0 vs. 83.7 ± 1.1 %, p=ns). Furthermore, over the range of submaximal workloads, nomads compared with Lhasa residents had lower $\dot{V}O_2$ ($p<0.01$), lower heart rates ($p<0.01$), and lower ventilation ($p<0.01$) and SaO_2 ($p<0.05$). We conclude that Tibetans living at 4400m compared with those at 3658m achieve greater work performance for a given $\dot{V}O_2$ at submaximal and maximal workloads, with less cardiorespiratory effort. This research was supported by NSF grant #BNS8919645 and a University of Colorado-Denver faculty research grant.

15.8

ALTITUDE TRAINING WITHOUT ACCLIMATIZATION: EFFECT ON SEA LEVEL WORK PERFORMANCE, SUBSTRATE UTILIZATION AND MUSCLE OXIDATIVE CAPACITY. BD Levine, K Engfred,* DB Friedman, M Kjaer, B Hanel, NH Secher, B Saltin. UT Southwestern, Dallas, TX 75235, and August Krogh Institute, Copenhagen, DK

Altitude training may improve exercise performance at sea level (SL) via acclimatization or a specific effect of hypoxic exercise. To determine whether hypoxic training alone improves substrate utilization or muscle oxidative capacity in large muscle groups, we studied 21 fit but untrained subjects before & after cycle ergometer training 5 days/week for 5 weeks. Group 1 trained at SL at 70% SL VO_2max. Two groups trained at simulated altitude of 2500m: group 2 trained at 70% altitude VO_2max (same relative workload); group 3 trained at the same absolute workload that would require 70% VO_2max at SL (same absolute workload, greater relative workload). Muscle biopsies (vastus lateralis) were obtained at rest & exhaustion during a submaximal endurance test at 85% pretraining SL VO_2max. **Results**: All 3 groups increased VO_2max (14.5 ± 2.3, 14.7 ± 2.0, 11.2 ± 1.7%) with no difference among groups. Endurance time improved most in group 1 (68 ± 12 min vs 39 ± 8 & 43 ± 5 *min*, $p<0.05$). Muscle glycogen was depleted less at a slower rate, & muscle & arterial lactate concentrations were lower at exhaustion after training, with no difference among groups. Similarly, citrate synthetase activity increased significantly (39.6 ± 9.7, 54.7 ± 6.7, 28.0 ± 5.6%, ANOVA p=0.08) in all 3 groups, while lactate dehydrogenase activity did not change. **Conclusion**: Hypoxic training without altitude acclimatization does not improve SL work performance, substrate utilization, or aerobic enzyme activity more than normoxic training in untrained subjects.

15.9

CAN ALTITUDE VO2MAX AND ENDURANCE PERFORMANCE BE PREDICTED FROM SEA LEVEL MEASURES? Anthony Sucec, Brad Roy* and James Hodgdon. Department of Physical Education, San Diego State and Naval Health Research Center, San Diego, 92182

It has been shown in the literature that moderate hypoxia (AL) exerts a variable influence on fit athlete's VO2max when compared to sea level (SL) values. This fact has lead some experts to contend that the best SL performer may not be the best at (AL). Thus our purpose was to investigate the relationship of VO2max (measured by computer-based spirometery), one-mile (1MI) and two-mile runs (2MI) at SL and acute AL (2-4 d) in 19 young distance runners (12 males & 7 females) with a mean age of 19 yrs and SL VO2max of 61.3 ml/kg/min. Their mean 1MI and 2MI times at SL were 5.20 and 11.26 mins, respectively. After two d at 8,000 ft (PB=576 Torr), the Ss were measured for VO2max and the 1MI and 2MI on separate days. The effect of the acute, AL was the reduction of VO2max to 54.1 ml/kg/min and the 1MI and 2MI times to 5.96 and 12.46 mins, respectively. All measures demonstrated reliable changes as the result of AL with correlations of .91 (Syx=2.9 ml/kg/min) for VO2max and .91 and .98 for the 1MI (Syx=.23 mins) and 2MI (Syx=.27 mins). The Syxs cited above agree well with the literature for SL as do the test-retest reliability coefficients. It is concluded that VO2max, 1MI and 2MI at SL well predict the same measures made at moderate AL.

15.10

SEASONAL CHANGES IN AEROBIC POWER AND AEROBIC CAPACITY IN NON-ELITE CYCLISTS. P. Barbeau & M.R. Boulay. Physical Activity Sciences Laboratory, Laval University, Ste-Foy, Qué., Canada G1K 1P4

Six non-elite cyclists (72.4±6.7 kg, 19±3 yrs) participated in this study (after signing an informed consent form) whose purpose was to identify cardiorespiratory and metabolic variables which could be used to monitor cyclists' evolution during a training and competition season. To this end a maximal aerobic power (MAP) test was performed four times during the season (Nov, Feb, May, Aug). Submaximal heart rate (HR) and ventilation (Ve) were lower in May ($p<.05$), but oxygen consumption ($\dot{V}O_2$) and gross mechanical efficiency did not change during the season. $\dot{V}O_2$max increased by 11% during the season, but HRmax did not vary. A 90-min maximal aerobic capacity (MAC) test was performed in Nov, Feb and Aug. HR and $\dot{V}O_2$ did not vary during the season. Although most comparisons were statistically non-significant due to a small sample size, lactate and the norepinephrine/epinephrine ratio decreased during the season, glucose, epinephrine and norepinephrine levels were higher in Nov compared to Feb and Aug, and the glycerol profile was improved in Aug. These tendencies indicated an increased utilisation of lipids during the season, resulting in a glycogen-sparing effect. Therefore, although a MAP test does not yield much information on the progress of cyclists during the season, a MAC test may yield more interesting information on the metabolic adaptations which occur during a season and thus be a useful tool to monitor training over long periods of time.

15.11

EFFICACY OF STAIRCLIMBING EXERCISE. A LOOK AT POSTOPERATIVE LEG RESPONSE. Michael C. Meyers, R. David Calvo, Robert R. Marley, T. Keith Duhon and James C. Sterling. Texas Sports Science Institute, Sugar Land, TX 77478

The increased use of stairclimbing devices to improve fitness has recently been promoted as an alternative to stationary cycling for knee rehabilitation in the injured athlete. However, the efficacy/response in an actual postoperative sports rehab population has not been established. The purpose of this on-going study was to quantify and compare leg response in 37 patients (25 males, 12 females; age 25.4±2.5 yrs; wt 70.4±13.7 kg) following postoperative anterior cruciate ligament (ACL) rehabilitation using a stationary cycle (C;n=17) or a stairclimbing (S;n=20) regimen. Following written informed consent, athletes were randomly assigned to either S or C programs previously matched by METS and heart rate. Isokinetic testing (KINCOM) was performed at 1 wk and 3 mth postop to determine mean and peak concentric quadriceps (CQ), eccentric quad (EQ), concentric hamstring (CH) and eccentric hamstring (EH) strength. Pre/post leg girths (cm) were measured (+3, +6, +9,-3,-6,-9 inches above/below the superior/inferior poles of the patella). MANOVA indicated no significant differences ($p>.05$) in strength gains (NM) between C and S groups, respectively, in mean CQ (42.6±15.5 vs 61.4±12.5), peak CQ (37.1±18.6 vs 76.0±15.0), mean EQ (82.2±19.0 vs 56.2±15.3), peak EQ (111.2±27.5 vs 67.0±22.1), mean CH (6.6±5.7 vs 16.1±4.6), peak CH (21.5±9.6 vs 26.8±7.7), mean EH (30.4±12.1 vs 31.0±9.8) or peak EH (45.0±16.2 vs 35.4±13.0). A significant increase ($p<.04$) in -6 (midcalf) leg girth was found among the S group (0.7±0.3 vs 0.1±0.3). No differences were noted in other girth measurements [(+3)1.1±0.5 vs 1.9±0.5; (+6)2.4±0.5 vs 2.2±0.5; (+9)2.7±0.5 vs 2.7±0.5; (-3) 0.3±0.3 vs 0.7±0.3; (-9)0.3±0.3 vs 0.9±0.3]. Early results indicate that stairclimbing compares favorably with cycling in the exercise process. The effects of long-term articular stability have not been addressed.

15.12

IMPROVEMENTS IN TREADMILL, CYCLE, AND ARM ERGOMETRY FOLLOWING CYCLE AND RUN TRAINING IN SEDENTARY FEMALES. B. C. Ruby, R. A. Robergs, G. W. Leadbetter, C. M. Mermier, T. W. Chick. Univ. of New Mexico, Albuquerque, NM 87131

To determine the training effects associated with central and peripheral adaptations, previously sedentary females (N=18) were assigned to one of three (n=6) training groups (run=R, cycle=C, both run and cycle=B). Training occurred 4 days/week for a total of 10 weeks at 70-85% heartrate reserve. Tests for $\dot{V}O_2$ max and lactate threshold (LT) were performed during treadmill running (TR) and cycle ergometry (CE) prior to (0T) and after training for 10 weeks (10T). During arm ergometry (AE) max tests, blood lactate ([La]) and heart rate (HR) were determined at 20 and 40 watts (W).

	TR		CE	
DV (N=18)	0T	10T	0T	10T
$\dot{V}O_2$ max ($l \cdot min^{-1}$)	2.35±0.05	2.56±0.07†*	2.15±0.06	2.37±0.07†*
VO2@LT ($l \cdot min^{-1}$)	1.79±0.06	2.13±0.06†*	1.44±0.05	1.74±0.07†*
HR@LT ($b \cdot min^{-1}$)	165±2.63	175±3.11†*	153±3.42	160±3.14†*

† $p<0.05$, (0T vs. 10T), * $p<0.05$, (TR vs. CE)

$\dot{V}O_2$ max, $\dot{V}O_2$@LT and HR@LT were significantly improved after 10T with no significant differences between the three training groups. All dependent measures were significantly greater for TR than CE. Although there were no significant improvements in AE $\dot{V}O_2$ max, HR was reduced from 134±3.32 to 124±2.42 and 154±3.37 to 142±2.67 at 20 and 40 W, respectively. Neither of the three groups showed significant reductions in [La] at 20 and 40 W during AE. Based on the MANOVA results, it is apparent that mode specific improvements do no occur in previously sedentary females. This data provides further evidence that cross-training between cycling and running results from peripheral adaptations (VO2@LT) with limited central improvements.

15.13

OPTIMIZING EXERCISE INTENSITY. G.R. GREENWELL. LIFE CLINIC, BRANDON, FL 33511 OPTIMUM INTENSITY(IN) OF EXERCISE FOR THE $\dot{V}O_2$ DELIVERY SYSTEMS TO DEVELOP AND MAINTAIN THE BEST HEALTH POSSIBLE IS THE IN THAT CHALLENGES THE $\dot{V}O_2$ METABOLIC CAPACITY OF THE WEAKEST TISSUE INVOLVED IN THE EXERCISE. THIS IN IS SLIGHTLY LESS THAN THAT WHICH WILL CAUSE THIS TISSUE TO DEVELOP EXPONENTIALLY INCREASING ACIDOSIS WHILE FUNCTIONING AT A CONSTANT IN 20 TO 30 MIN. IF A SEGMENT OF THE MYOCARDIUM IS THE WEAKEST TISSUE INVOLVED, IT WILL BE NECESSARY TO CONTINUOUSLY, REAL TIME, MONITOR THE ECG FOR SIGNS OF ACIDOSIS DEVELOPMENT, SUCH AS S-T OR RHYTHM CHANGES. SKELETAL MUSCLE UTILIZED SLIGHTLY EXCESSIVELY AT CONSTANT IN WILL CAUSE INTRACELLULAR ACIDOSIS AND CO_2 EXCRETION RATE, BLOOD LACTATE, CARDIAC OUTPUT AND PULSE RATE TO INCREASE EXPONENTIALLY. TO DETERMINE THE OPTIMUM IN BASED ON PULSE RATE THE SUBJECT SHOULD EXERCISE AT THE IN THAT CAUSES THE PULSE RATE TO BE APPROXIMATELY 75% OF A PRE-DETERMINED SAFE MAX$\dot{V}O_2$ AND MAINTAIN THIS CONSTANT IN UNTIL SIGNS OF INTRACELLULAR ACIDOSIS, OR THE 20 TO 30 MINUTE PERIOD IS REACHED. THE IN SHOULD BE ADJUSTED ONCE DAILY UNTIL THE MAXIMUM CONSTANT IN PULSE RATE IS IDENTIFIED. THOSE LIMITED BY CARDIAC METABOLISM SHOULD BE EVALUATED UNTIL THEY APPEAR TO HAVE REACHED MAXIMUM POSSIBLE MYOCARDIAL METABOLISM OR UNTIL THE MYOCARDIUM METABOLISM EXCEEDS THAT OF THE SKELETAL MUSCLES, OTHERS EVERY 2 TO 3 YRS. THIS PROCEDURE HAS DEMONSTRATED IN OVER 500 PEOPLE THAT THE RATE OF INCREASING FUNCTIONAL CAPACITY IS USUALLY 20% TO 50% IN 3 WEEKS.

15.14

NATIONALLY RANKED PAIRS SKATERS POSSESS AVERAGE LEVELS OF FITNESS. ET Mannix, A Healey* and MO Farber*. Indiana Univ Sch of Med, Methodist Hospital and VAMC, Indpls IN 46202.

We reported that a group of unranked figure skaters (n=15, X±SE age=13.9±0.6 y) possessed average fitness compared with age/gender matched, non-athlete controls (FASEB J 6(4):1235, 1992): when cycle training was added to on-ice workouts of 7 skaters for 10 weeks fitness gains were observed: the other 8 did not improve fitness with on-ice training alone. We have now measured fitness variables of nationally ranked pairs skaters (Grp 1, n=16, age=16.3±0.9 y) and compared their peak O2 uptake (VO2p), anaerobic threshold (AT) and supramaximal exercise times (SUPMX) with the pre-training data from the 15 unranked skaters (Grp 2). No significant differences were noted in VO2p (Grp 1: 45.8±1.5, Grp 2: 47.2±2.3 ml/kg/min), AT (Grp 1: 80.9±3.3, Grp 2: 76.7±2.1% of VO2p) or SUPMX (Grp 1: 1.15±0.13, Grp 2: 1.07±0.13 min): Grp 1 also had average VO2p expressed as % predicted (98.4±2.5%) which did not differ from Grp 2 (104.5±45%). After training the 7 Grp 2 skaters displayed higher ($p<0.05$) levels than Grp 1 for VO2p (55.9±33 ml/kg/min), VO2% predicted (121±6%), AT (83±2%) and SUPMX (2.69±0.66 min). We conclude that these nationally ranked pairs skaters are of similar fitness compared to unranked figure skaters before cycle training and that off-ice training should be considered to improve fitness and potential for success in international competitions.

15.15

A PHYSIOLOGICAL/PSYCHOLOGICAL INDICATOR OF OVERTRAINING. A. C. Snyder, A. E. Jeukendrup*, M. K. C. Hesselink* and H. Kuipers* Univ. Wisconsin - Milwaukee and Univ. Limburg, Maastricht, The Netherlands.

Both physiological and psychological measures have been proposed as indicators of overtraining. The purpose of this study was to test the hypothesis that a decrease in the ratio of plasma lactate concentration (HLa) to ratings of perceived exertion (RPE) would indicate an overtrained state. METHODS: Well trained male cyclists (n=7) performed two weeks each of: normal training, overtraining and recovery. An incremental exercise test to maximal effort was performed during each training period with HLa and RPE obtained at the end of each workload. RESULTS: All subjects became overtrained. The ratio of HLa:RPE (multiplied by 100) decreased for all workloads following one (-29.1 $\pm$ 3.0%) and two (-48.7 $\pm$ 2.5%) weeks of overtraining. The decrease at the maximal workload was statistically significant. For all subjects, when overtrained, the maximal RPE was greater than the maximal HLa (HLa:RPE ratio less than 100). The ease and speed at which the HLa:RPE ratio can be determined makes it useful for coaches and athletes in monitoring exercise training.

A. C. Snyder was a Fulbright Scholar at the Univ. of Limburg during the performance of this study.

15.16

EIGHTEEN MONTH PROFILE OF CARDIOVASCULAR FITNESS IN YOUNG MALE WRESTLERS. C.D. Rodgers, J.L. VanHeest, W.D. VanHuss, and V.D. Seefeldt. Department of Physical Education and Exercise Science, Michigan State University, East Lansing, MI 48824

To date, the implications of chronic wrestling training on cardiovascular fitness are not well documented. The purpose of this pilot study was to determine a profile of the effects of wrestling training on cardio- vascular parameters in young wrestlers (N=30; age=13 yrs) over an eighteen month period. At four timepoints (0,6,12,18 months) measures of cardiovascular fitness (HR, BP, VO2, lactate) were assessed using an intermittent (3:3 min-work:rest) treadmill protocol. The data suggests that a significant (p<.05) training effect occurred in both HR (Stage 2:0M=192$\pm$2;6M=181$\pm$2; Stage 3:0M= 200$\pm$2;6M=191$\pm$2bpm) and VO2 Stage2:0M=42.6$\pm$0.6;6M=38.4$\pm$0.7; Stage3:0M=50.6$\pm$0.7;6M=46.1$\pm$0.6 ml/kg/min) over the first seascn, only at submaximal levels. No differences were evident in BP or lactate at either submax. or ma:.. l. vels. Over the second season (12-18M) no differences in any of the parameters measured were observed, although a trend suggests a plateau or slight decline in the cardiovascular fitness of the boys. Results of this pilot work suggest that wrestling training can stimulate aerobic conditioning initially as determined by alterations in performance at submaximal workloads yet maximal performance is unchanged. Morever, the impetus for change does not appear to provide significant chronic overload of the aerobic system in trained young males thereby enhancing the aerobic capacity of the participants.

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DISEASE STATES

16.1

SKELETAL MUSCLE FUNCTION AND ION FLUX IN CYSTIC FIBROSIS

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Skeletal muscle performance is affected by alterations in the plasma electrolytes (Lindinger and Heigenhauser, Am J Physiol 1988;254:R117). During exercise, plasma ion concentrations are modulated by the erythrocyte (McKelvie et al, Can J Physiol Pharmacol 1991;69:984). It is unclear whether defects in electrolyte transport exist in blood cells from Cystic Fibrosis (CF) patients (Boucher et al, Ped Res 1984;18:1336; Chen et al, Science 1989;243:657). We hypothesized that these defects might affect skeletal muscle performance during intense exercise. Seven well nourished CF patients were compared to 7 healthy age-matched control subjects. Skeletal muscle performance was assessed during a 30-s sprint on an isokinetic cycle ergometer. Ion flux was evaluated by sampling from arterialized venous blood at rest, at peak exercise, and after 5 minutes of recovery. Sprint performance did not differ between the CF (total work: 93.7$\pm$30.02% predicted; endurance: 30.6$\pm$9.93 % decline) and control (109.7$\pm$19.48; 35.6$\pm$14.76) groups. The changes in plasma and erythrocyte ions and blood gases did not differ between the groups. However, the contribution of decreases in the strong ion difference to increases in [H$^+$] was less in the CF group, primarily due to a smaller increase in lactate concentrations. This may be due to alterations in ionic flux in CF but the influence of inadequate arterialization of the blood samples could not be ruled out. The CF patients' responses to progressive exercise do not suggest a difficulty with lactate release from exercising muscle.

Supported by the Canadian CF Foundation

16.2

SLOWER PHOSPHOCREATINE RESYNTHESIS RATES IN MULTIPLE SCLEROSIS. J.A. Kent-Braun, K.R. Sharma, M.W. Weiner, R.G. Miller. UCSF/VA & Calif. Pacific Med. Ctrs., San Fran., CA. 94121

Previous studies have suggested that the muscle fatigue common in multiple sclerosis (MS) may be due in part to a metabolic deficit within the muscle. The purpose of this study was to measure the rate of recovery of phosphocreatine (PCr) after exercise to determine whether oxidative metabolism is impaired in MS. Thirteen MS patients underwent 9min of intermittent tetanic contractions of the tibialis anterior muscle elicited by stimulation of the peroneal nerve (240ms every 3sec, 50Hz). Eight healthy control subjects (C) performed voluntary exercise which resulted in metabolic changes similar to those in the MS group. Intracellular PCr and pH were measured continuously using a 1.9T magnetic resonance spectroscopy unit. PCr resynthesis rate was determined during the first 5min of recovery using a mono-exponential corrected for extent of depletion. The patients were divided into two sub-groups demonstrating 1) fast (MS-F) or 2) slow (MS-S) PCr recovery. At the end of exercise, there were no differences between groups in either [PCr]; C: 16.5$\pm$4.6mM, MS-F: 18.2$\pm$5.0mM, MS-S: 20.2$\pm$9.0mM, (mean$\pm$SD) or pH; C: 6.77 $\pm$0.50, MS-F: 6.79$\pm$0.15, MS-S: 6.72$\pm$0.36. The $t_{0.5}$ of PCr recovery was C: 46.2$\pm$7.8sec, MS-F: 40.3$\pm$15.8sec, MS-S: 126.4$\pm$69.9sec. The MS-S group was significantly slower to recover than both the C and MS-F groups ($p<0.05$). The data indicate that some MS patients have impaired oxidative capacity which may explain their excessive muscle fatigue.

16.3

AEROBIC TRAINING EFFECTS IN HEMIPARETIC STROKE PATIENTS. K. Potempa, M. Lopez*, L. Braun, P. Szidon*, A. Folta*, T. Tinknell, M. Yee*. University of Illinois at Chicago, Chgo, IL. 60612

The purpose of this study was to document the aerobic trainability and related physiologic effects in hemiparetic stroke subjects (Ss). Twenty-two Ss, mean age 59 (SD=11), with similar levels of physical disability and initial levels of fitness (peak VO_2) were randomly assigned to ten-weeks of aerobic training on an adapted bicycle ergometer (AT) or ten-weeks of passive range of motion (PROM) exercises, 3 times per week for 30 min. Ss in the AT group showed a significant increase (11.6%) in peak VO_2 (ml/kg/min^{-1}), whereas the PROM group showed no changes. AT Ss also showed increases in post-training exercise time (p=.03) and peak workload (p=.03). There were no reductions in submaximal HR or diastolic BP in either group, but a significant reduction in systolic BP (27 mmHg, p=.01) was observed only in AT Ss. These results demonstrate that modest improvements in aerobic capacity and exercise systolic BP can occur in hemiparetic stroke patients with adequate training, which may have important influences on functional ability and cardiovascular risk management.

16.4

ISOMETRIC QUADRICEPS FUNCTION IMPROVES AFTER SPINAL CORD STIMULATION INDICATED FOR INTRACTABLE LEG PAIN

S.L. Griffith, G.M. Bogdanffy, D.D. Ohnmeiss, R.F. Rashbaum. Texas Back Institute Research Foundation, Plano, Tx. 75075

Chronic intractable pain often results in the inability to lead a normal, active life. Physical function is limited in patients exhibiting intractable leg pain. Spinal cord stimulation (SCS) is a surgical procedure in which electrodes are placed over the spinal cord in the thoracic spine, emitting electric impulses to inhibit neural sensory transmission from the legs to brain. The reduction in pain afforded by this proceedure can potentially result in a more favorable quality of life. The purpose of this study was to evaluate quadriceps function following SCS. Sixteen patients (mean age 47.5yrs) were treated for intractable leg pain by SCS. Leg function was evaluated isometrically (10sec. effort) on a Lido Active Dynamometer at 50° of knee extension. Impulse values (ft/lbs*sec) were adjusted for body weight (BW). An age and sex matched, asymptomatic group (n=16) was used as the control. One year after SCS, the more painful leg showed a significant from 39% of control values to 55% of control values ($p<0.05$). The less painful leg showed an increase in function from 49% to 71% ($p<0.05$). Control values were 7.20 and 7.50(impulse/BW, in the nondominate and dominate leg. These data show that isometric quadriceps testing can be used to evaluate objective changes in a clinically compromised population and that SCS can reduce pain such that leg function is improved, but not totally restored.

16.5

CARDIORESPIRATORY RESPONSES OF THE SPINAL CORD INJURED TO THREE MODES OF EXERCISE.

D. Lium, R. Robergs, J. Krauss*, B. Price*, and J. Depape*. Human Performance Lab. Univ. of New Mexico. Albuquerque, NM. 87131

The cardiorespiratory responses of eight (7 male, 1 female) spinal cord injured subjects were evaluated during Computerized Functional Electrical Stimulation leg ergometry (CFES LE), arm ergometry (AE), and a combination of the two (HYB). Data were collected following six weeks of CFES LE training and six weeks of HYB training. The heart rate (HR), oxygen consumption (VO_2), respiratory exchange ratio (RER), minute ventilation (VE) and caloric expenditure (KCAL) data area presented in the table below.

	CFES	AE	HYB
Peak HR	112±11*	165±9 †§	130±11*
Peak VO_2 (ml/min)	819.60±72.2*§	1296.2±154.9†	1386.2±131.0†*
Peak RER	0.87±0.04*	1.10±0.05†§	0.87±0.03*
Peak VE (L/min)	39.0±4.7	61.6±7.9	49.3±5.5
Peak KCAL	4.01±0.36*	6.53±0.78†	6.78±0.65†

† p<0.05 from CFES LE, * p<0.05 from AE, § p<0.05 from HYB

The greater HR response for AE exercise versus both CFES LE and HYB confirms previous research indicating an impaired venous return. The higher VO_2 and KCAL expenditure during HYB exercise can be attributed to the greater muscle mass being used as compared with CFES LE exercise. The results of the present study indicate that hybrid exercise elicits the greatest acute cardiorespiratory response and thus supports this mode of exercise as the most beneficial to cardiorespiratory function in the spinal cord injured.

16.6

EXERCISE TRAINING ATTENUATES DIABETES-INDUCED CIRCULATORY DYSFUNCTION IN RATS. W.L. Sexton Department of Physiology, Kirksville College Osteopathic Medicine, Kirksville, MO 63501.

To determine whether exercise training can attenuate the diabetes-induced alterations in circulatory control, male Sprague-Dawley rats were randomly divided into sedentary (SC) and exercise trained (EC) control, and sedentary (SD) and exercise trained (ED) diabetic (65 mg/kg STZ iv) groups. EC and ED rats trained 60 min/d on a treadmill at 18 m/min, 20% grade for 12 wks. Mean arterial pressure (MAP), heart rate (HR), and hindlimb muscle (MF) and gut (GF) flows (ml/min; microspheres) were measured at rest (R) and after 8 min of exercise (E).

	n	BW	[G]	R-HR	R-MAP	R-MF	R-GF	E-HR	E-MAP	E-MF	E-GF
SC	(9)	436	163	408	134	4.2	19.1	519	134	18.8	6.0
SD	(9)	260*	498	320*	101*	1.9*	36.5*	435*	126	15.9*	14.6*
EC	(10)	426	171	413	129	3.8	19.3	516	129	20.9	11.8*
ED	(11)	308*	397#	348	114#	3.1#	37.0*	440*	127	16.5*	21.9*#

* P≤0.05 vs C and ETC. # P≤0.05 vs SD. BW, body weight; [G], plasma [glucose].

Resting HR, MAP, and hindlimb muscle flow were lower in diabetics, but gut flow was doubled. During exercise, HR and muscle flow were lower in diabetics, but MAP was not different from control. Exercise training attenuated the diabetes-induced reductions in resting MAP and muscle flow, but not the exercise responses. Gut flow was reduced less during exercise in both trained groups. These data indicate that exercise training improves circulatory function in diabetic rats and confirms an important role for exercise in the management of diabetes.

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16.7

VANADYL SULFATE EFFECTS ON GLUCOSE OXIDATION IN ISOLATED CARDIAC MYOCYTES FROM STREPTOZOTOCIN DIABETIC RATS. S.J. Kopp, J.T. Daar. Chicago College of Osteopathic Medicine, Department of Physiology, Downers Grove, IL 60515

The hypothesis that vanadyl sulfate (0.5-0.6 mg $VOSO_4$/ml) administered orally (V_{suppl}) would suppress the chronic metabolic complications of insulin-deficient diabetes mellitus was tested in male Sprague-Dawley rats made diabetic with streptozotocin (60mg/kg). Control and diabetic rats were randomly assigned to one of two groups: non-supplemented or V_{suppl}. Following excision of hearts for myocyte isolation, blood samples were taken for plasma glucose, triglycerides, total cholesterol, HDL cholesterol and glycosylated hemoglobin. All blood metabolic profiles of diabetic rats were improved significantly with V_{suppl}. Analysis of glucose oxidation by isolated cardiac myocytes revealed significantly less basal and insulin-stimulated (10^{-8} M) glucose oxidation in hearts from diabetic rats (3.914±1.011 nmoles/mg/min) relative to control (9.073±1.011 nmoles/mg/min). V_{suppl} to diabetic rats did not affect basal glucose oxidation (5.086±0.603 nmoles/mg/min); however it significantly enhanced insulin stimulated glucose oxidation [(*Control non-supplemented*: 8.924±.911; (*Control*+V_{suppl}: 7.060±.99); (*Diabetic non-supplemented*: 4.418±.524); (*Diabetic*+V_{suppl}: 6.999±0.587 nmoles/mg/min)]. Endogenous glycogen and lactate levels detected in the cardiomyocytes from the various groups showed no significant differences. These results indicate that oral V_{suppl} preserved the ability of cardiac myocytes to utilize glucose and respond to insulin stimulation.

16.8

SPONTANEOUS EXERCISE ALLEVIATES MUSCULAR DYSTROPHY IN DIAPHRAGM OF MDX MICE. Esther E. Dupont-Versteegden and Roger J. McCarter. Dept. Physiology, UT Health Science Center San Antonio, Texas 78284-7756.

In contrast to hindlimb muscles, diaphragm muscle in mdx mice exhibits signs of muscular dystrophy comparable to human Duchenne muscular dystrophy. The purpose of this study was to investigate effects of spontaneous running exercise on diaphragm (DIA) and soleus (SOL) muscle performance in vitro. Dystrophic (mdx) and control (C57BL/ScSn10) mice were kept in cages with and without running wheels and were allowed to exercise freely from 3 weeks to 10 months of age. Wheel revolutions were counted with magnetic counters attached to the wheels. After sacrifice SOL and DIA were dissected and tied to stainless steel rings with surgical silk. Maximal isometric tetanic tension (P_O), contraction time (CT), half relaxation time (HRT), and fatigue index (F_I) were measured in vitro in curarized Ringer solution (pH 7.4, 23C) with direct stimulation via platinum electrodes. Spontaneous running activity in mdx was 50% of control for the ages 12 to 28 weeks. Before 12 weeks and after 30 weeks of age mdx running activity was 80% of control. Spontaneous exercise did not change CT, HRT, and F_I in mdx and control for both muscles. P_O was not changed in control DIA and control SOL. However in exercized mdx mice P_O of DIA was significantly increased (by 36%). P_O in mdx SOL increased, but not significantly (p=0.07). Results indicate that muscular degeneration in mdx diaphragm can be retarded by spontaneous exercise.

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16.9

EFFECTS OF PULMONARY EMPHYSEMA ON DIAPHRAGM MICROVASCULAR GEOMETRY David C. Poole and O. Mathieu-Costello. Dept. of Med., UCSD, San Diego, La Jolla, CA 92093-0623

Pulmonary emphysema augments lung compliance and mechanically disadvantages the diaphragm. Respiratory muscle work is increased and the diaphragm undergoes enhanced oxidative enzyme capacity (Lewis et al. J. Appl. Physiol. 72: 934-943, 1992) and reduced fiber length by loss of sarcomeres in series (Farkas and Roussos, J. Appl. Physiol. 54: 1635-1640, 1983). This investigation determined how the diaphragm capillary-to-fiber geometry responds to the structural (loss of sarcomeres) and energetic (increased diaphragm $\dot{V}O_2$) changes which attend the emphysematous condition. Male hamsters underwent endotracheal elastase (group E, n=6) or saline (group C, n=5) instillation 5 months before sacrifice. Diaphragms were glutaraldehyde perfusion-fixed in situ at airway pressures of -25, 0 or +25 cmH_2O and analyzed morphometrically. The range of sarcomere lengths (l) was reduced in E (2.55 to 2.90 μm) compared with C (2.22 to 3.07 μm). When l was normalized to 2.5 μm there was a significantly reduced diaphragm capillary number per fiber area in the emphysematous hamsters (E=2831±103, C=3448±126 mm^{-2}, P<0.05) but capillary length per fiber volume, $J_V(c,f)$, was not different (E=3894±172, C=4024±109 mm^{-2}). Thus, at a given l capillary tortuosity and branching components tended to contribute more to $J_V(c,f)$ in the emphysematous animals. One benefit of this behavior is that it conserves capillary length per fiber volume and possibly diaphragm gas exchange potential in the face of reduced fiber length and increased O_2 demand. Support: TRDRP (2KT 0066) and NIH (HL-17731).

16.10

AEROBIC AND ANAEROBIC EXERCISE CAPACITIES OF CHILDREN WITH JUVENILE RHEUMATOID ARTHRITIS. D.C. McKenzie, P. Malleson*, S.P.D. Turner*, D.K. Jespersen*, J. Tekano*, K.D. Coutts. University of British Columbia, Vancouver, B. C., Canada.

Due to the nature of the disease, children with Juvenile Rheumatoid Arthritis (JRA) are often forced to withdraw from normal physical activities. In order to examine and understand more fully the impact of this disease on the exercise capacities of this population, we studied 27 children with JRA (15 males, age 12.9 ± 2.3; 12 females, age 13.1 ± 3.2 years) and 13 Control subjects (C) (9 males, age 12.8 ± 3.2; 4 females, age 13.0 ± 2.6 years). Althought the height and weight measurements for JRA males and females (159.8 ± 15.2 cm, 49.1 ± 14.7 kg; 152.8 ± 12.5 cm, 48.5 ± 14.2 kg) were lower than C (162.0 ± 18.8 cm, 51.3 ± 17.2 kg; 155.7 ± 8.8 cm, 55.8 ± 12.8 kg) the difference was statistically not significant. Peak power in the Wingate Anaerobic test (WAn) was lower for both JRA males and females relative to C (8.5 ± 1.9 vs 9.3 ± 1.9 W/kg; 6.8 ± 1.3 vs 7.0 ± 0.9 W/kg), as was the total work performed during this test (10.1 ± 5.1 vs 11.9 ± 6.1 kJ; 7.8 ± 3.1 vs 8.4 ± 2.4 kJ). Aerobic capacity was lower for both JRA males and females in comparison to C (42.4 ± 7.9 vs 47.6 ± 8.5 ml/kg/min; 32.1 ± 6.1 vs 33.8 ± 8.7 ml/kg/min) but the difference was statistically not significant. It is evident that children and adolescents who are being treated for Juvenile Rheumatoid Arthritis have lower exercise capacities than their counterparts in the normal population.

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16.11

MUSCLE EDEMA AFTER ECCENTRIC EXERCISE. Kazunori Nosaka and Priscilla M. Clarkson. Yokohama City University, Yokohama, Japan 236 and University of Massachusetts, Amherst, MA 01003

Soreness, decreased muscle function, and increased muscle proteins in the blood are well documented indicators of muscle damage. Relatively little data exist on muscle swelling after such exercise. This study examined muscle edema using measures of circumference (CIR), ultrasonography (USG), and magnetic resonance imaging (MRI) after 14 college age males performed 24 maximal eccentric actions of the forearm flexors. CIR was measured at 4 sites on the upper arm, and USGs using 7.5MHz linear probe were taken from the upper arm. Measures were taken pre and for 5 days post-exercise. On a subsample (n=6), MRI was performed on the upper arm using a 0.5-T supraconducting unit with a circular polarized receive-transmit coil, and measures were taken pre and 1, 3, 6, and 10 days post-exercise. Established indicators of muscle damage (forearm flexion isometric strength, range of motion, muscle soreness level, plasma creatine kinase, glutamic oxaloacetic transaminase, and C-reactive protein <CRP>) were also measured pre and for 5 days post-exercise. These muscle damage indicators, except CRP, changed significantly ($p<.01$). A large increase in CIR (26.0 ±14.0mm, peak) was found 4-5 days post-exercise and this coincided with USG showing an increase in the distance from the skin to the humerus and an increase in echogenicity. MRI showed enlargement of the biceps and brachialis cross-sectional areas, peaking at 6 days post-exercise, and an increase in signal intensity on T2-weighted and proton density images that were more conspicuous at 6 or 10 days post-exercise. Subjects who showed greater changes in muscle damage indicators also showed greater incidence of edema, although the time course of the changes differed among the measures. The most profound edemic changes occurred after muscle function had begun to recover.

16.12

EFFECTS OF TRAINING ON MUSCLE BLOOD FLOW RESPONSE TO EXERCISE IN HYPOTHYROID RATS. Richard M. McAllister, Michael D. Delp, and M. Harold Laughlin. College of Veterinary Medicine, University of Missouri, Columbia, MO 65211.

We have previously reported that hypothyroidism is associated with reduced blood flow to high oxidative muscle fibers during exercise (*Med Sci Sports Exer* 24:S117, 1992). We hypothesized that exercise training would restore normal blood flow. To test this hypothesis, rats were made hypothyroid with propylthiouracil and then trained on a treadmill at 30 m/min (15% grade) for 60 min/d, 5 d/wk over 10-12 wk. Efficacy of training was indicated by a 60% increase ($P<0.001$) in citrate synthase activity in plantaris m. in trained hypothyroid rats (T-HYPO, 26.16±1.51 μmol/min/g) over sedentary hypothyroid animals (HYPO, 16.20±1.64). Regional blood flow was determined by the microsphere method in HYPO (n=5) and T-HYPO (n=5) rats of similar size during pre-exercise standing and at 1-2 min of treadmill running at 15 m/min (0% grade). Pre-exercise blood flows were unaffected by training. Muscle blood flows during exercise were also similar between groups for red vastus lateralis m. (HYPO, 159.3±15.5 ml/min/100 g; T-HYPO, 164.3±48.8), white vastus lateralis m. (HYPO, 23.4±5.5; T-HYPO, 23.0±7.5), and soleus m. (HYPO, 166.3±17.0; T-HYPO, 183.5±42.3). Mean arterial pressures during exercise were unaffected by training (HYPO, 106±8 mmHg; T-HYPO, 112±4). These findings do not support our hypothesis and indicate that exercise training does not normalize reduced high oxidative muscle blood flow during exercise in hypothyroid rats. Further, these data suggest that left ventricular function is not improved with training and may account for these findings.

Supported by NIH grant HL-36088, a grant from U. of MO COR, and a fellowship from AHA, MO affiliate.

16.13

BLOOD FLOW AND FATIGUE RESISTANCE IN SOLEUS MUSCLES OF SPONTANEOUSLY HYPERTENSIVE RATS (SHR). Jun Deng*, Nguyen Kien* and Sarah D. Gray. University of California, Davis 95616

In previous studies, we have shown that fatigue resistance in soleus muscles from 6 month old SHR was significantly lower than in normotensive WKY rats. In the current study, we used radioactive microspheres to determine whether differences in muscle blood flow (BF) might underlie the differential response to a fatigue stimulus. At rest, one of two labelled microspheres (^{85}Sr, ^{141}Ce) was injected into the left ventricle of Na-pentobarbital anesthetized animals via a right carotid artery cannula; an arterial blood sample was taken from the left renal artery. During 4 mins stimulation of the cut tibial nerve (20-25 Hz for 330 ms, 1 train/s) to induce fatigue, the 2nd microsphere was given and an arterial sample was taken during the last 1.5 mins of contraction; muscles and other tissues were sampled and counted. Fatigue indices (CFI and PFI) were significantly different in the 2 strains. Soleus mean BF (ml/min x 100g) was slightly higher in SHR at rest (WKY= 6.37 ± 0.77; SHR= 7.31 ± 0.69) and after denervation (WKY= 23.02 ± 2.25; SHR= 28.37 ± 5.85), but slightly lower than WKY during fatiguing exercise (WKY= 61.34 ± 7.81; SHR= 49.10 ± 8.50). Although BF differences were not significant, they were consistent. Vascular resistances (mm Hg/ml/min x 100g) for the 2 strains however, were significantly different during all 3 flow states: at rest (WKY= 14.64 ± 1.70; SHR= 20.74 ± 1.87), after denervation (WKY= 4.01 ± 0.31; SHR= 7.00 ± 1.87) and during fatiguing exercise (WKY= 1.77 ± 0.25; SHR= 3.96 ± 1.12). The data suggest that the hemodynamic state of the muscle is different in the 2 strains and SHR soleus muscle is not able to reduce the high vascular resistance to the same degree as WKY during a hyperemic stimulus, thus ↓BF may be related to the increased fatiguability in SHR. (NIH grant HL42463).

16.14

EVALUATION OF POST-EXERCISE HYPOTENSION USING NALOXONE METHIODIDE. K.A. Monnin, L.A. Sebastian, P.K. Edwards, and C.M. Tipton, University of Arizona, Tucson, AZ 85721

The existence of post-exercise hypotension after acute exercise is well documented in hypertensive populations. Previously, we reported (*The Physiologist* 36: 124, 1991) reductions, regardless of the training state of the animal, in mean arterial pressure at either 30 min (-16±3 mm Hg) or 60 min (-17±4 mm Hg) of recovery from 25 min of treadmill exercise at 70% VO_2 max. As expected, naloxone hydrochloride (N•HCl; 1 ml/kg) prevented the decline in pressure in both the nontrained and trained animals. However, since N•HCl influences both central and peripheral opioid receptors, the site of action in the prevention of post-exercise hypotension by N•MI remained unknown. Therefore, we infused either naloxone methiodide (N•MI; 5 mg/kg) or saline into the jugular vein of hypertensive rats (SHR) after the completion of an exercise test. N•MI was used because published reports indicate that it cannot cross the blood-brain barrier. The MBP results, recorded from the carotid artery, were as follows (values are means±SE; *significantly different from pre-exercise, $p\leq0.05$):

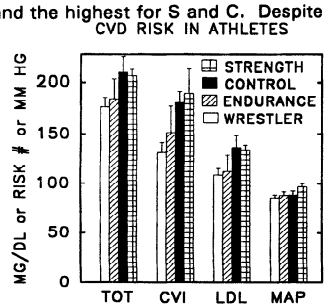
		Pre-exercise	Post-exercise	
Condition	N		20 min	40 min
Saline	18	180±4	162±6*	169±5
Naloxone M.I.	16	169±5	156±6*	155±5*

These findings suggest that the prevention of post-exercise hypotension by N•HCl occurs because of its central action on the opioid receptors. Future studies that incorporate central infusions and hemodynamic measurements will provide insights into the responsible mechanisms. (Supported in part by NHLB grant HL-33782-04.)

16.15

DO ALL MODES OF EXERCISE MINIMIZE CARDIOVASCULAR DISEASE RISK? V. Pat Lombardi and Dennis R. Taaffe. University of Oregon, Eugene, OR 97403

To examine the impact of exercise mode on cardiovascular disease (CVD) risk, we administered a comprehensive CVD risk profile including total (TOT) and low-density lipoprotein (LDL) cholesterol, mean arterial pressure (MAP), and CVD inventories (CVI) to 28 young adult males: endurance-trained (E) and strength-trained athletes (S), wrestlers (W), and controls (C). A unique continuum was displayed across all CVD risk variables, with the lowest CVD risk for W and E and the highest for S and C. Despite consistent energy expenditures exceeding thresholds established for lowering CVD risk, the training regimens and/or dietary habits of strength-trained athletes place them at a CVD risk greater than or equal to that of inactive subjects. These data demonstrate the need for longitudinal studies which closely examine the interrelationship of exercise mode and diet on CVD risk.



16.16

EFFECTS OF AEROBIC EXERCISE AND DIET HIGH IN MONOENES ON PLATELET AGGREGATION AND THROMBOGENESIS. Rainer Rauramaa, Tuomo Rankinen*, Sari Väisänen*, Esa Mylylä* and Ilkka Penttilä*. Kuopio Research Institute of Exercise Medicine, 70110 Kuopio, Finland.

The aim of the study was to analyze the effects of exercise and diet intervention on thrombogenesis. 120 men aged 51 to 53 years were randomly assigned to either reference group, or to three exercise groups (2, 4 or 6 weekly exercise sessions), or to diet group, or to combination of exercise (4 times a week) and diet. Training intensity was individually prescribed with training heart rate around the aerobic threshold. Training program consisted of aerobic exercise plus stretching. Diet intervention was aimed at replacing, as much as possible, saturated fats by rapeseed oil products, which contain 60 % monoenes. During the trial monoenes contributed 14.3 % of total energy intake in diet and diet plus exercise group. The duration of the intervention was six months. Blood sampling took place one week after stopping the exercise program, whereas monounsaturated diet continued until blood donation. No statistically significant between group differences were evident in any measures of platelet aggregation, in plasma fibrinogen, Factor VIIa, antithrombin III or in tissue plasminogen activator activity. The present data suggest that the responses of platelet aggregation, blood coagulation factors and fibrinolysis to aerobic exercise, if any, are a temporary phenomenon in men of normal body weight. High monoene diet do not seem to modify thrombogenetic properties.

16.17

EFFECT OF EXERCISE AND CONDITIONING ON FACTOR VIII COMPLEX AND PLATELET AGGREGATION IN MAN. M. S. El-Sayed. Crewe and Alsager College of HE, Cheshire, England.

The purpose of this study was to evaluate the acute and chronic effects of exercise on Factor VIII-coagulant (FVIII-C), Factor VIII-related antigen (FVIII-RA), platelet count (PC) and platelet aggregation. Following one week of familiarization, 24 subjects (12 male, 12 female) were divided into exercise (E) and control (C) groups matched according to cardiorespiratory fitness. Resting values and post maximum exercise (bicycle ergometer) responses of FVIII-C, FVIII-RA, PC and platelet aggregation (adenosine-diphosphate [ADP] induced) were evaluated in both groups before and after a 12-week conditioning programme. Group E exercised (bicycle ergometer) 20 min x 3 per wk, while group C maintained normal activity patterns. The conditioning programme was of graduated intensity and employed an intensity of 70% (first 6 wk) and 80% (latter 6 wk) maximum heart rate. A significant increase ($p<0.05$) in FVIII-C, FVIII-RA and PC was observed in response to maximum exercise before and after the conditioning programme in both groups. Maximum exercise did not alter ($p>0.05$) ADP-induced platelet aggregation. Although post conditioning VO_2 max was significantly increased ($p<0.05$) in E vs C, no significant changes in basal level, nor responses to maximum exercise, were observed. It is concluded that vigorous exercise increases Factor VIII complex and induces thrombocytosis, but does not alter platelet aggregation. Furthermore, conditioning appears not to affect the haemostatic parameters measured.

EXERCISE TESTING

17.1

VALIDATION OF A LIGHT WEIGHT PORTABLE DEVICE FOR MEASURING OXYGEN UPTAKE DURING SPACE FLIGHT. Phillip Bishop, Stuart Lee, Michael Greenisen*. NASA Exercise Countermeasures Project, Johnson Space Center, Houston, TX 77058

Assessment of oxygen uptakes (VO_2) of humans and animals who are mobile is difficult. We evaluated the accuracy and utility of a small, portable, light-weight (800g) battery-powered telemetry system (PMS) for measuring VO_2 during space flight. Ventilation measurements agreed closely with a mechanical calibrator and a reference system (RS) (R^2=.99-1.0). Measures of VO_2 (n=78) were compared in humans between the PMS and a mass-spectrometer based RS over a broad range of VO_2's and for 30 min at a constant work rate. Agreement between systems was maximized by:

VO_{2ref}= .942*VO_2PMS_{raw} -.055 R^2= .973; S_{yx}=.148

Drift in VO2 measures were acceptable in relation to time and across the range of VO_2's. The PMS was comfortable for the subjects even for prolonged use. With the above equation, the PMS VO_2's were sufficiently accurate for most applications including space flight and may also be adaptable to animals of appropriate size. The PMS appeared to be highly portable, comfortable, rugged, mechanically reliable, and useful for many research applications.

17.2

RESPONSES DURING SIMULATED COMPETITION. Carl Foster, Megan Green, Ann C. Snyder and Nancy N. Thompson. Sinai Samaritan Medical Center, Milwaukee, WI. 53233

Laboratory studies with competitive athletes often use graded exercise protocols (GXT) to elicit physiologic responses. This pattern of power output is different than ordinarily employed by athletes during competition. In order to understand the physiologic responses during competition, we studied 12 athletes (speed skaters, cyclists, triathletes) during simulated competition, a 5 km time trial (TT) on a racing bicycle attached to a windload simulator, and during cycle ergometer GXT (n=8). During TT the velocity pattern was similar to "real world" competitions and the subjects indicated that the TT was perceptually similar to competition. Physiologic responses were of significantly greater magnitude vs GXT (VO_2 max: 3.46 ± 0.73 vs 3.27 ± 0.79 l/min), VE max: 138 ± 27 vs 119 ± 22 l/min, HR max: 184 ± 11 vs 175 ± 11 b/min, HLa: 14.8 ± 3.7 vs 11.9 ± 2.1 mm). All physiologic measures increased steadily throughout the TT (km 0,1,2,3,4,5: Vo_2 = 1.03, 2.95, 3.42, 3.69, 3.82 & 3.92 l/min; HR = 93, 175, 181, 185, 189 & 194 b/min; V_E = 31, 99, 120, 129, 145 & 156 l/min; HLa = 2.9, 5.6, 7.2, 9.2, 10.6 & 13.5 mM). In 6 subjects (speed skaters), the peak values observed during TT for HR (188 ± 6 vs 191 ± 5 b/min) and HLa (16.4 ± 3.1 vs 17.0 ± 4.2 mm) were not significantly different than observed during "real world" competition. The results demonstrate that the physiologic responses demonstrated by athletes under competitive conditions may be significantly greater than suggested by conventional laboratory testing and that ergometric protocol may be an important element in laboratory studies with athletes.

17.3

PREDICTING VO_{2max} FROM A SUBMAXIMAL TEST IN AEROBICALLY TRAINED AND UNTRAINED MEN. Larry P. Krock, G. Harley Hartung, Roger U. Bisson, Craig G. Crandall and Loren G. Myhre. Crew Technology Division, Armstrong Laboratory, Brooks AFB, TX 78235.

Introduction: The USAF recently implemented a modified Astrand-Rhyming submaximal cycle ergometry (SCE) test to assess physical readiness. This study was conducted to estimate validity of this SCE test for predicting VO_{2max} by comparing test results to laboratory treadmill determinations of VO_{2max} for high fit and sedentary men. **Methods:** Twenty-two male subjects, (11 trained and 11 sedentary) performed a SCE test, modified to adjust workload in early stages to a target steady-state HR at end of test. Also VO_{2max} was measured by indirect calorimetry during a continuous progress running protocol (Astrand). **Results**: Differences between groups were not significant for most physical characteristics; however, the high fit group was less fat than inactive subjects ($p<.05$). SCE systematically underestimated treadmill measurements in all subjects. This error was greater in low fit (23%) than in active subjects (12%). Reliability of SCE predicted VO_{2max}, to that of determined VO_{2max}, was acceptable (R=0.95). However, standard error of the estimate was 4.25 ml/kg/min. Difference between methods was 7.4 ml/kg/min for the active and 8.8 ml/kg/min for the inactive group. **Conclusion**: Individual estimates are subject to error. Using SCE to predict aerobic capacity is valid. Controlling sources affecting HR response during submaximal exercise may improve precision of the estimate.

17.4

SUBMAXIMAL CYCLE ERGOMETRY ESTIMATES OF AEROBIC CAPACITY IN A TEST OF A NEW AIR FORCE FITNESS PROGRAM. Roger U. Bisson,* Larry P. Krock and Loren G. Myhre. Armstrong Laboratory, Brooks AFB, TX 78235

INTRODUCTION. We report the first year experience using a submaximal cycle ergometry (SCE) estimate of aerobic capacity (AC) to motivate nearly 1000 active duty personnel to adopt more active lifestyles. Under this program, members who fail to meet minimum standards select an individualized conditioning strategy and are evaluated quarterly. Repeat estimates help focus intervention strategies and track individual trends. **METHODS:** AC was estimated by a heart rate regulated incremental workload protocol. Those testing below defined fitness standards entered individual or supervised conditioning programs. Low fit members were evaluated at 5, 9 and 12 months. Scores were correlated with multiple demographic variables. **RESULTS:** On initial testing, 35.2% met the desired standard. At 9 months, 58.7% had achieved the standard and 23.9% were enrolled in supervised conditioning. Complaints of misclassification errors were an initial barrier to acceptance, but repeat measures usually reflected expected conditioning effects or showed good reproducibility. **CONCLUSIONS:** Operating characteristics of SCE were satisfactory. Demographics show high potential for epidemiologic correlation. At one year, SCE appears to have motivated lifestyle changes and improved fitness at this installation.

17.5

NEW AIR FORCE CARDIOVASCULAR FITNESS TEST: ITS DEVELOPMENT, IMPLEMENTATION, AND FIELD-EVALUATION FOR OPERATIONAL TASK RELEVANCE. Loren G. Myhre. Armstrong Laboratory, Brooks AFB TX, 78235.

INTRODUCTION. On 1 Oct 92 the US Air Force will replace the annual 1.5 mile run with an adaptation of the Astrand-Ryming method for assessing cardiovascular fitness (VO2 max) by cycle ergometry. The implementation of this technology, culminating more than ten years of research and development, will unequivocally reduce the risk while enhancing the validity of fit-for-duty testing of Air Force personnel. This paper summarizes a series of studies to (1) evaluate the validity and reliability of a precise protocol for administering submaximal cycle ergometry to a large and physically diverse population, and (2) study the relationship between these test scores and true physical performance capability in simulated strenuous operational tasks. METHODS. A random sample of 1124 male and 348 female Air Force personnrl were tested to develop valid population norms for this specific test. Additional samples of 192 Air Force Firefighters and 68 groundcrew assigned to training for rapid runway repair activities were tested to provide a basis for relating ergometer test scores to the level of performance observed for specific operational tasks. Determinations of VO2 max during exhaustive exercise by standard indirect calorimetry were performed on a smaller sample of men (n = 12) to provide a means of comparing the criterion measure with predictions obtained from cycle ergometry. RESULTS. The distribution of test scores by submaximal cycle ergometry was not significantly different from that expected for a large, normal population. Thus, test score norms were developed with a high level of confidence (P<.01). Reliability of test-retest scores for n = 642 was excellent; values obtained on different days agreed within an average of 1.2 ml/kg/min in predicting VO2 max. Scores predicted by submaximal cycle ergometry were highly correlated (r = 0.91) with those determined by indirect calorimetry for exhaustive exercise. CONCLUSION. Aerobic capacity can be validly and reliably predicted using a precisely standardized protocol for submaximal ergometry. Norms developed from this relatively large sample of military personnel may be of considerable value to civilian populations as well.

17.6

ESTIMATION OF MAXIMAL OXYGEN UPTAKE FROM SUBMAXIMAL EXERCISE TESTING IN WOMEN. G. Harlev Hartung, David A. Lally, Roberta J. Blancq* and Larry P. Krock. Univ. of Hawaii at Manoa, Honolulu, HI 96822

Simple, valid and reliable methods of estimating maximal oxygen uptake(VO_{2max}) are needed in epidemiologic studies of physical activity and to assist in prescription of exercise. Such estimations in women have not received due research attention. Heart rate(HR) responses to submaximal cycle ergometry and VO_{2max} during treadmill testing were measured in 37 healthy women aged 19-47 yr(x=31.4± 8). The submaximal test was very reliable on retest(r=.92), but overestimated measured VO_{2max}(x=2.46 vs 2.24 L.min-1; r=.77, standard error of estimate[SEE]=.299). Multiple regression analysis yielded an equation which included submaximal estimate of VO_{2max} and body weight with an R^2 of .74 and SEE .241. For VO_{2max} normalized for body weight, the equation included estimated VO_{2max}, self rating of physical activity, % body fat, and rating of perceived exertion on the submaximal exercise test, yielding an R^2 of .70 and SEE of 3.6 ml.kg-1.min-1. A simple submaximal exercise protocol provides reliable test-retest estimates of VO_{2max} when used for women. It also provides a reasonably good estimate of measured VO_{2max}, especially if other easily measured variables are included in a prediction equation. Supported by the Air Force Office of Scientific Research.

LOCOMOTION AND BIOMECHANICS

18.1

USE OF THIGH MUSCULATURE IN THE SQUAT EXERCISE. L.L. Ploutz and G.A. Dudley. NASA Kennedy Space Center, FL 32899

It is difficult to determine involvement of individual muscles in a given activity because of their limited access for surface or indwelling EMG. Magnetic resonance images (MRI), in contrast, provide unparalleled visualization of individual muscles and show exercise-induced contrast shifts which scale with work intensity and EMG activity. Accordingly, we examined contrast shifts in MR images to assess involvement of thigh muscles in squat exercise. We tested the hypothesis that the number of joints a muscle crosses and its apparent functional requirement determine its involvement in the squat. Eight experienced weight trainees performed six sets of 10 repetitions of the squat with a resistance that induced failure within each set. Multiple echo, transaxial, T_2 weighted MR images (1.5T, TR/TE:2000/30, 1 nex, 256x256 data set, 1cm thick at 0.5 cm intervals) were collected between the knee joint and head of the femur before and immediately post exercise to determine involvement of the vasti (VS), adductor (ADD), and hamstring (HAM) muscle groups, and the rectus femoris (RF) muscle. The area of muscle showing an elevated T_2 was greater ($P<0.05$) for VS, ADD, and RF, when compared to control (walking). 91% (84±3.7 cm^2) of the VS were used in the squat, compared to 66% (46±3.18 cm^2) of ADD, and 68% (4.77±1.9 cm^2) of RF. The HAM showed no change in area of muscle with an elevated T_2 ($P>0.05$). We conclude that the thigh muscles are differentially involved in squat exercise. These differences support our hypothesis in that single joint knee extensors (VS) showed the most involvement, even compared to their multi-joint counterpart (RF).

Supported by a NASA grant administered under contract NAS10 11624

18.2

RUNNING SPRINGS: EFFECTS OF SPEED AND BODY SIZE. Claire T. Farley* James Glasheen* and Thomas A. McMahon.* (SPON: R. E. Full). Harvard University, Cambridge, MA. 02138

Running, hopping and trotting animals bounce along the ground using musculoskeletal springs to store and return elastic energy. In this study, we examine how the musculoskeletal springs are adjusted to operate at different speeds and in animals of different sizes. The model which we use consists of a leg spring and a mass that alternately bounces off the ground and flies through the air (McMahon & Cheng, 1990). We find that the stiffness of the leg spring is nearly independent of speed in dogs, goats, horses and red kangaroos. This finding agrees with the earlier finding of He *et al.* (1991) that the stiffness of the leg spring (k_{leg}) is independent of speed in running humans. All of these animals spend less time in contact with the ground at higher speeds simply because of adjustments in the geometry of the leg spring during the stance phase. Analysis of a wider size range of animals (0.1 to 140 kg) at equivalent speeds reveals that larger animals have stiffer leg springs ($k_{leg} \propto M_b^{0.69}$). The longer ground contact times of larger animals can be explained in terms of the resonant period of vertical vibration which is determined by the stiffness of the leg spring, leg spring geometry and body mass.

Supported by N.I.H. grant # RO1 AR 18140.

18.3

GENERALITY OF A SPRING-MASS MODEL IN PREDICTING THE DYNAMICS OF MANY-LEGGED, TERRESTRIAL LOCOMOTION. R.J. Full and R. Blickhan*. Univ. of Calif., Berkeley, CA 94720 and Universität des Saarlandes, D-6600 Saarbrücken, FRG

Despite impressive variation in leg number, length, position and type of skeleton, similarities of legged, pedestrian locomotion exist in energetics, gait, stride frequency and ground-reaction force. A bouncing, spring-mass, monopode model can approximate the dynamics of trotting, running, and hopping in 2-, 4-, 6-, and 8-legged animals. From the mechanical-energy fluctuation of an animal's center of mass and ground-reaction force, we calculated the compression of a monopode's virtual leg and its stiffness. Dimensionless parameters revealed that locomotor dynamics depend on gait and leg number, but not body mass. Surprisingly, relative stiffness per leg was similar for all animals and appears to be a very conservative quantity. Differences in the general dynamics of gait are based largely on the number of legs acting simultaneously to determine the total stiffness of the system. Trotters (quadrupeds and hexapeds) had a greater whole body stiffness than runners (bipeds). Since trotters and runners operated their systems at about the same relative speed, the greater whole body stiffness in trotters resulted in a smaller compression of the virtual leg and a higher stride frequency. Congruence with a spring-mass model supports the hypothesis that musculo-skeletal systems operate as springs during terrestrial locomotion. Supported by NSF Grant PYI DCB 90-58138 to RJF.

18.4

A METHOD FOR CONTINUOUSLY MONITORING GROUND REACTION FORCES DURING DAILY ACTIVITY. Jeff L. Emery* and Robert T. Whalen* (SPON: Alan R. Hargens). NASA/Ames Research Center, Moffett Field, CA 94035

Theoretical models and experimental studies of bone remodeling suggest that bone density and structure are functions of local cyclic skeletal tissue stress histories. To test our theoretical model and further investigate the influence of mechanical forces on bone density, we have focused on the calcaneus as a model site loaded by calcaneal surface tractions which are predominantly determined by the magnitude of the external ground reaction force (GRF). We have now developed instrumentation to monitor and record GRFs during normal daily activity in order to obtain daily calcaneal loading histories. *Methods:* The vertical component of the GRF is sensed and logged using a capacitive insole force transducer and portable data recorder. Computer algorithms reduce the stored GRF data to yield relevant GRF characteristics: number of load cycles, peak cyclic loads and ranges, cyclic mean forces, and daily duration at a force magnitude. *Results:* Data from a routine, non-exercising day of a working male adult revealed that, based on *duration*, the calcaneus is rarely loaded above ~1.0 BW (9 min. or 1% of the non-resting day). However, ~41 % of the daily *load cycles* had a range of ~1.0 BW or greater, whereas ~45 % were equal to or below a range of ~0.5 BW. Importantly, the sensor was able to detect the few higher force (1.5 - 1.9 BW), non-normal walking load cycles which contribute significantly to the daily bone maintenance stimulus. Sensor data used to estimate daily walking cycles and digital stepmeter readings, recorded simultaneously, were within 3 % of each other. *Conclusion:* Measurement of daily GRFs promises to be a valuable method for quantifying physical activity in terms of external loading histories with applications to muscle and bone maintenance and adaptation with age and exercise.

18.5

A MATHEMATICAL MODEL FOR THE ESTIMATION OF HIDDEN MASS DISPLACEMENT IN PERIODIC MOVEMENTS. A.E. Minetti* and G. Belli° (SPON: P. Cerretelli). *I.T.B.A. C.N.R., °Dept. of Mathematics, Politecnico di Milano, Milano, Italy, 20131.

When calculating the mechanical external work of locomotion, different results can be obtained, depending on the adopted techniques. While the speed changes of the body centre of mass are "truly" sensed by dynamometric platforms, only an approximated dynamics can be inferred from the geometry of the cinematographically measured segments, since the presence of an internal moving mass (abdominal and thoracic viscera), hidden from the cameras, affects the position of the body centre of mass. Such a noise in locomotion energetics turns out to be the signal in the field of locomotor-respiratory coupling. In fact, in the galloping horse and dog, the synchronous displacement of the internal mass (the visceral piston) with respect to the trunk (the container) is regarded as one of the determinants of locomotion-assisted breathing. This study presents a methodology which, starting from the dynamometric records of the ground reaction force and from detailed cinematographic measurements of the container, calculates the relative motion of the hidden mass with respect to the container. The derived equation for the vertical displacement, assuming a periodic movement (with or without an aerial phase), and knowing in advance the value for the hidden mass (m), is:

$$s(t)-s(0)=\frac{M+m}{m}\left\{\left[\int_0^t dt\int_0^t\left(\frac{\Phi(t)}{M+m}-g\right)dt-\frac{t}{T}\int_0^T dt\int_0^t\left(\frac{\Phi(t)}{M+m}-g\right)dt\right]-\left[y_1(t)-y_1(0)\right]\right\}$$

where M is the mass of the rest of the moving system, $\Phi(t)$ is ground reaction force (vertical component), g is gravity acceleration, T is cycle duration, y_1 refers to the vertical position of the body centre of mass (cinematographically estimated). Similar relation for horizontal displacement has been obtained. The method has been tested with a subject rhythmically raising and lowering a load while standing on a force platform. When applied to periodic vertical jump, assuming m of about 9 kg, this method reveals an excursion of the visceral mass in the range of 5-8 cm, with an out-of-phase oscillation with respect to the body movement .

18.6

Stroke Profile Analysis on a Modified Concept II Rowing Ergometer. R.F.T.Kinch*; R.P.Craven*; D.F. Parker*; S.J.Walter*[1]. (SPON: D.L. Turner) School of Biological and Molecular Sciences, [1] Computer Services, Oxford Polytechnic, Gipsy Lane, Headington, Oxford, OX3 OBP, England.

The use of ergometers for the physiological evaluation of sportsmen is well established. The Concept II rowing ergometer provides a close approximation to the movements of the rowing stroke and allows accurate measurements of the physiological changes produced by the work. However, it does not permit evaluation of the technical ability of an oarsman. We have developed a system using a modified Concept II rowing ergometer, which records the force profile at the hands and feet, the speed of the seat and flywheel. Strain gauges are inserted between the handle and chain and beneath the stretcher to measure the forces applied during the stroke. The movement and speed of the seat is recorded photoelectrically. Flywheel speed is monitored using the Hall effect transducer supplied with the Concept II. The signals are converted into D.C. Voltages (0.0-2.0V) and sampled at 100Hz using a 12 bit resolution PC Labs Analogue to Digital Converter mounted in a Research Machines VX25, IBM AT compatible microcomputer. Rate, length, power and catch are computed for every stroke throughout the work. Force profiles from the hands and feet enables analysis of the coordination of the work done by the arms and legs. A graphical summary of this data and their mean values may be displayed. To date our ergometer-based stroke analysis system has been used as an aid to coaching and selection of rowers from Oxford University Boat Club and the British Amateur Rowing Association National Squad.

18.7

TORQUE AND THE ENERGETICS OF SWIMMING THE FRONT CRAWL.
R. G. Soule*, A. Cigalotto, C. Capelli, P. Zamparo, M. Girardis,. Dep. of Science and Biomedical Technology, Section of Physiology, School of Medicine, University of Udine, 33100 Udine, Italy.

Pendergast et al. (77) reported that underwater Torque (T,N*m^{-1}), i.e. a measure of the tendency of the body immersed horizontally to assume the vertical position, in a group of technically homogeneous swimmers of both sexes was linearly related to the energy cost of crawl swimming per unit distance (C_s, kJ*m^{-1} per m^2 of BS). Using a recently developed "Torque Balance" to measure T (Soule et al., 92), the effects of T on C_s were investigated in a group of 10 swimmers (4 females: 167 cm±2.1; 61.0 kg±5.4; 1.67 m^2±0.02; 6 males: 184 cm±6.0; 77.0 kg±4.4; 1.99 m^2±0.06) measuring C_s at constant aerobic speed (~0.7 m*s^{-1}) after having purposely modified T by securing around the subjects' hips a polyethylene tube containing 1 or 2 kg of lead (T increases), water (T remains unchanged) or air (T decreases). It was observed that C_s is a linear function of T in all subjects (r^2: 0.894±0.063; range: 0.962±0.784). These data confirm the view that T is one of the major determinates of C_s. In addition, we suggest that the slope of the individual functions ($\Delta C_s/\Delta T$) is a quantitative assessment of the subjects' skill to overcome T, regardless of their anthropometric characteristics.

R. G. Soule on leave from Biola University, La Mirada, CA

18.8

RUNNING UPHILL: WHY ARE SMALL ANIMALS LESS EFFICIENT? David S. Wu* and C. Richard Taylor. C. F. S., Museum of Comparative Zoology, Harvard University, Old Causeway Road, Bedford, MA 01730.

Small animals are less efficient at running up hills than large ones. Mice and rats are able to reach maximal efficiencies of only about 5% in converting their metabolic energy into work, compared to 20-30% in humans, dogs and horses. The muscles that perform this work reach efficiencies of 20-30% *in vitro*. We asked, Why don't small animals reach these high values *in vivo*, where it matters? Maximal efficiency occurs when muscles shorten at about 0.2-0.3 of their maximal shortening velocity, V_{max}. Small animals use faster muscles and their maximal efficiencies occur at higher work rates, in direct proportion to the V_{max} of active muscles. We hypothesized that small animals are not working hard enough to reach their maximal efficiencies when they run uphill. To test this idea we compared two birds that differed in weight by 30-fold, 0.12 kg quails and 3.5 kg turkeys. We measured efficiency and the time of force application by each foot, t_c, over a range of speeds and inclines. We assumed 1/tc was proportional to V_{max} . At their equivalent speeds (where ground force per body weight is similar for both animals), the quails used fibers 1.79 times faster than the turkeys and ran at slower speeds (.6 m/s vs 1.0 m/s). The quails would have to work at 3.0 times harder to reach the same efficiency. As predicted, we found that the efficiency was the same when the ratio of work rate to V_{max} was the same, irregardless of speed or incline. Supported by NIH Grant RO1 AR 18140.

18.9

IS IT CHEAPER TO WALK THAN TO RUN? Christine M. Stoffel*, Jennifer E. Bihldorff*, Rodger Kram, Thomas Roberts* and C. Richard Taylor. C.F.S., Museum of Comparative Zoology, Harvard University, Old Causeway Road, Bedford, MA 01730

If we walk a mile, our muscles use only half as much energy than if we run the same distance. We asked, is this also true for quadrupeds? Both bipeds and quadrupeds use the same energy-saving mechanisms: an inverted pendulum for walking and springs for running. Thus, we might expect the same two-fold difference in energetic cost between walking and running. We measured oxygen consumption when animals stood quietly and over a range of walking speeds. We also measured stride frequency and the rate at which each foot applied force to the ground, 1/time of foot contact, $1/t_C$. We compared dogs (30 kg), goats (31 kg), llamas (107 kg), ponies (168 kg) and elephants (1542 kg). We calculated rate of energy consumption using an energetic equivalent of 20.1 J/mlO_2. The amount of energy the muscles used in moving each newton of body weight a meter was calculated by dividing net energy consumption (walk-standing) by speed (the cost of transport). Cost of transport is independent of speed during running, but not during walking. Therefore we compared the minimum cost of walking which occurred at the same duty factor (0.65) in all of the animals. We found that it cost 1.6 ± se 0.17 times as much to run as to walk in dogs, goats, ponies and llamas, and elephants did not run. We also found that the cost coefficient for generating a newton of force on the ground was also 1.6 ± se 0.19 times as great. We suggest that the lower cost of walking is due to straighter legs and a better mechanical advantage for generating force on the ground. This work was supported by NIH Grant RO1AR18140 and NSF IBN-8918371.

18.10

TWO STEPS FOR THE PRICE OF ONE: ENERGETICS OF BIPEDAL AND QUADRUPEDAL RUNNERS. Michael S. Chen*, Thomas J. Roberts*, Ted Goslow Jr.*, and C. Richard Taylor. C.F.S., Museum of Comparative Zoology, Harvard University, Old Causeway Road, Bedford, MA 01730.

Longer legs of large runners result in better fuel economy. Large animals cover a mile in fewer strides, and on a per weight basis, the cost per stride at equivalent speeds is independent of size. For a given size, a biped's legs are twice as long as a quadruped's. Yet the cost of running for bipeds is not cheaper. Why is this so? We hypothesized that bipeds use more muscle to run. To test this idea, we compared dogs (4.5 kg) and wild turkeys (5.3 kg). We measured energy consumption of running animals and muscle force at each limb joint (using a force platform, high speed video, and anatomical measurements). At equivalent speeds (2.0 m/s for the dog and 3.5 m/s for the turkey) where duty factor and ground force/body weight were the same (1.27 for the dog and 1.24 for the turkey), we calculated volume of active limb muscle from fascicle length and cross-sectional area assuming maximal isometric force (30 N/cm^2). The turkey required 3 times as much limb muscle to produce a newton of force on the ground, helping to explain the higher cost per stride in the turkey (0.81 J/(N•stride)) as compared to the dog (0.44 J/(N•stride)). The larger volume of muscle was the result of both longer muscle fascicles (1.8 times) and a poorer mechanical advantage (0.6 times) in the turkey. We conclude that bipeds run for twice the cost per stride because they use a greater volume of muscle to generate force on the ground. This work was supported by NIH Grant RO1 AR 18140, NSF IBN-8918371 and a NSF Graduate Fellowship to Thomas Roberts.

18.11

EXERCISING INTERMITTENTLY ALTERS DISTANCE CAPACITY IN THE LIZARD *TERATOSCINCUS PRZEWALSKII*.

R.B. Weinstein* and R.J. Full. Univ. of California, Berkeley, CA 94720

Most laboratory studies of animal locomotion have focused on physiological responses to continuous treadmill exercise, yet many animals move intermittently. We have examined the importance of rest pauses on locomotor performance limits by exercising lizards (9.8 g) continuously and intermittently on a treadmill. Lizards exercised continuously at 0.3, 0.6, and 0.9 km/hr (90%, 180%, and 270% of the maximum aerobic speed, respectively). At an exercise speed of 0.9 km/hr, lizards exercising intermittently with a 15 sec exercise duration (E) and 30 sec pause duration (P) exhibited an 11-fold increase in distance capacity (total distance traveled before fatigue) compared to lizards exercised continuously at 0.9 km/hr and a 2-fold increase in distance capacity compared to lizards exercised continuously at 0.3 km/hr (the same average speed). At an exercise speed of 0.6 km/hr, lizards exercising intermittently with both E and P = 30 sec or 120 sec did not exhibit an increase in distance capacity compared to lizards exercising continuously at the same average speed (0.3 km/hr). The aerobic cost of intermittent exercise was not significantly different from the maximal rate of oxygen consumption. These results support our observations in insects and crustaceans. Since moving intermittently can alter performance limits identified for continuous locomotion, physiological systems need to be re-evaluated with a focus on transitions.

18.12

NON-CONTACT MEASUREMENT OF ENERGY EXPENDITURE DURING STEADY-STATE AEROBIC EXERCISE.

N. J. Pogue*, R. A. Nelson and R. A. Boileau. Carle Foundation and Univ. of IL, Urbana, IL 61801

After 30 minutes of steady-state aerobic exercise, energy expenditure was estimated from the heat emitted plus energy consumed by treadmill walking. Heat was calculated by partitional calorimetry from mean skin temperature measured by infrared thermography (ITC). Energy expended during exercise was calculated based on treadmill grade plus the energy expended during level walking. Walking energy plus ITC was compared to periodic measurements of indirect calorimetry (IC). Five trained males (T♂) ran 40±14 mi/wk for the past year, while 5 active males (A♂) of similar age and height, ran 8.8±1 mi/wk. Exercise was treadmill walking at approximately 30% and 60% of the subject's maximal oxygen consumption ($\dot{V}O_{2max}$). After 30 minutes at 30% of $\dot{V}O_{2max}$, energy expenditures based on ITC plus walking energy were approximately equal to IC for both trained and active males (ITC 2.5%>IC). For 60% of $\dot{V}O_{2max}$ exercise, IC was consistently larger ($p<.01$) than energy expenditure based on ITC plus walking energy (A♂ IC 11%> ITC; T♂ IC 16%> ITC). This *suggested* continued heat storage which could be due to the non-preferred gait and speed selected for the study.

18.13

EFFECTS OF EXERCISE ON POSTURAL CONTROL FOLLOWING EXPOSURE TO SIMULATED WEIGHTLESSNESS.

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The effects of exercise on postural control (during walking) in four lower extremity muscles was evaluated following exposure to simulated weightlessness (6° head down tilt - HDT). Two groups of male subjects (mean age =21.4 years ± SE 1.0) were exposed to 5 days of HDT. One group remained HDT for 5 days with no intervention (C=6 subjects), while the second group exercised 90 minutes per day (E=12 subjects). EMG activity in the tibialis anterior (TA), gastrocnemius (GA), vastus lateralis (VL), and biceps femoris (BF) was collected during walking before (PRE) and after (POST) 5 days of HDT. Mean integrated EMG results (mv·sec ± SE) were as follows:

	PRE		POST	
	C	E	C	E
TA	754.0±8.0	753.1±5.7	775.0±3.7	777.1±3.5
GA	742.1±9.6	744.0±4.9	760.3±3.1	758.5±3.9
VL	714.6±9.2	716.0±5.2	735.1±2.0	736.1±1.2
BF	748.7±7.2	744.8±5.0	764.0±2.5	865.6±1.7

A two-way ANOVA was used to determine statistical significance. Following HDT, EMG activity increased significantly in both groups for all muscles ($p < 0.05$). However, there were no significant differences in EMG activity between the C and E groups following HDT. These data indicate that the ability of the neuro-vestibular system to adjust to the gravitational environment was compromised as a result of HDT. In addition, these data suggest that the exercise protocol used was not an effective countermeasure to the alterations in the neuro-vestibular system. Supported by NASA grant #NAG9-400.

PROTEIN METABOLISM

19.1

COLLAGEN SYNTHESIS IN DIABETIC AND TRAINED RATS.

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The activities of prolyl 4-hydroxylase (PH) and galactosylhydroxylysyl glucosyltransferase (GGT), both enzymes of collagen biosynthesis and hydroxyproline (Hyp) concentration were measured in vastus lateralis, rectus femoris and gastrocnemius muscle after 12-16 weeks of running in normal and streptozotocin-induced diabetic rats. Diabetes decreased collagen marker enzyme activities whereas training slightly increased their activities. In diabetic rats training was partially able to prevent the decrease of PH activity and in rectus femoris and gastrocnemius the specific activity of GGT was even increased above the control level. Hyp concentration decreased in vastus lateralis in the trained rats and increased in gastrocnemius in the diabetic trained rats.

The results suggest that in diabetic muscle atrophy collagen synthesis and balance follows the overall negative muscular protein balance. Training could prevent only partially the negative effects of diabetes. Therefore the lack of insulin is a more important regulator of muscular collagen synthesis than physical activity as such.

This study was supported by a grant from the Ministry of Education, Finland.

19.2

DEVELOPMENT OF TWO-CELL MOUSE EMBRYOS IN MEDIA CONTAINING GLUCOSE AND AMINO ACIDS.

Barbara Shirley. Univ. of Tulsa, Tulsa, OK 74104

Mouse embryos were cultured from the two-cell stage in media that contained glucose and in medium that contained L-phenylalanine, L-valine, L-isoleucine, L-tyrosine, L-tryptophan, and L-arginine to determine whether these compounds inhibit early development of mouse embryos as they do hamster embryos. Embryo development was assessed after 24, 48, and 72 hrs of culture. When glucose was the only potential energy source provided, embryo development was arrested at the two-cell stage, as expected, but when pyruvate was provided as well, development was not inhibited by the presence of glucose. Moreover, when media that contained pyruvate also contained either glucose or lactate, embryo development was enhanced after 48 hrs of culture. The amino acids tested, like glucose, had no effect on rate of embryo development in the first 48 hrs of culture but enhanced development after 48 hrs. It was concluded that mouse embryos, unlike hamster embryos, are not adversely affected by glucose and the six amino acids tested, that these compounds need not be excluded from media in which two-cell mouse embryos are cultured, and that the compounds can enhance later preimplantation development.

19.3

MAINTENANCE OF CARDIAC COLLAGEN RATIOS IN EXERCISE TRAINED RATS. Maria Lonnett Burgess, Francis L. Abel, Robert Price, Greg Jones, James Buggy and Thomas K. Borg. Univ. of South Carolina School of Medicine, Columbia, SC 29208

Chronic exercise training (X) and hypertension (H) are known to alter physiological and biochemical properties of the heart. Cardiac contractility and compliance are known to change in response to the physiological and pathological stimuli associated with X and H, respectively. These changes may be associated with cellular modifications in extracellular matrix (ECM) components. Scanning electron microscopy of left ventricles in both X and H showed an overall increase in total collagen accumulation in the ECM. Hydroxyproline analysis of total collagen confirmed this observation. However, the ratio of collagen types III:I was maintained in X (0.8), while it decreased in H (0.3). This decrease indicates accumulation of predominantly type I, fibrous (stiff) collagen in the cardiac ECM. In addition, an indice of diastolic compliance (-dP/dT=-13 vs. -5) was enhanced in X vs. H, respectively. Significant correlations between the cellular (collagen) and physiologic (±dP/dT) variables were observed (r=-0.90; p<0.05). These data suggest the possibility of an important role for adaptations in ECM components in the changes in cardiac function observed in both chronic exercise and hypertension.

19.4

PLASMA AND MUSCLE AMMONIA METABOLISM IN THE IN SITU CANINE GASTROCNEMIUS MUSCLE DURING 3 DIFFERENT TWITCH STIMULATION. **D.A.MacLean, J.K. Barclay and T.E. Graham. School of Human Biology, University of Guelph, Guelph Ont. Canada N1G-2W1**

Mongrel dogs (n = 15) were anaesthetized and the vasculature of the left gastrocnemius-plantaris muscle group was surgically isolated. The cut sciatic nerve was stimulated at 3, 4 and 5 Hz twitch while blood flow, arterial and venous blood samples were taken at rest 5, 15, 30, 45 and 60 min. Muscle biopsies were obtained at rest 5, 30 and 60 min. Muscle ammonia (NH_3) in umol/kg wet weight ($\bar{x}$ ± sem).

Time	3 Hz	4Hz	5Hz	
Rest	330(60)	286(51)	409(93)	* P<0.05 from
5 min	674(74)*	515(142)*	827(30)	5 Hz
30 min	621(102)	413(74)	794(264)	
60 min	530(71)	368(79)	640(152)	

At 5 min release had increased to 2.31±1.17, 1.31±0.21 and 3.5±0.68 umol/min.100g for the 3, 4, and 5 Hz groups, respectively (5 Hz> 3, 4 Hz, P<0.05). At 60 min the NH_3 release was 2.78±0.92, 1.39±0.26 and 1.56±0.36 umol/min.100g, for the 3 4 and 5 Hz groups respectively. All three frequencies caused substantial NH_3 production however, there were no significant differences between the 3 and 4 Hz groups.

Supported by NSERC

19.5

TRAINING AND MUSCLE AMMONIA AND AMINO ACID METABOLISM IN MEN DURING PROLONGED EXERCISE. **T. Graham, L. Turcotte*, B. Kiens* and E. Richter*. August Krogh Inst., Copenhagen, Denmark.**

We studied the responses of ammonia (NH_3) and amino acids (AA) to exercise (3h) in trained (Tr) (n=6) and untrained (UTr) (n=6) men. Each subject exercised the knee extensor muscles of one leg at 60% of their maximum capacity. Thigh blood flow and femoral arterial-venous differences (0,30,60, 120,150,180 min) as well as muscle biopsies (0,120,180 min) were taken for NH_3 and AA measurements. In both groups muscle glutamate decreased (p<0.05) and aspartate increased, (p<0.05) but the muscle AA pool, including the essential AA, remained constant despite a total AA efflux of 21.3 ± 11.6 and 15.3 ± 9.7 mmol·kg^{-1}w.w. in Tr and UTr respectively. Tr had greater (p<0.05) muscle taurine, phenylalanine, alanine and glutamate. Both groups had a large glutamate uptake and effluxes of NH_3, glutamine, alanine and essential AA. The latter implies that there was a net protein catabolism. Many of the AA responses were associated with the free glutamate pool and the Tr used this pool less (p<0.05) implying that they derived more glutamate from protein catabolism and/or AA transaminations. There was a large NH_3 production both as NH_3 and as glutamine as well as a net protein catabolism in both groups.

Supported by Danish Medical Research Council, Danish Natural Sciences Research Council, Danish Sports Research Council and Canadian Natural Science and Engineering Research Council.

19.6

HORMONAL REGULATION OF SKELETAL MUSCLE HYPERTROPHY IN A RAT HINDLIMB ABLATION MODEL

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Myofibrillar contractile proteins serve the body in two opposing roles: 1) as an energy transducer by interactions of actin and myosin, and 2) as a source for fuel in times of extreme demand. The interactions between the potent catabolic hormone corticosterone(C) and anabolic hormone testosterone(T) play an important part in determining which of these two roles myofibrillar protein plays. An ablation model, which involves the removal of the gastrocnemius muscle, was employed to induce hypertrophy in the remaining synergist plantaris muscle. Hormonal manipulations consisted of T-filled silastic implants(TI), empty implants(EI), and castration(CI). Plasma levels of C and T were determined by extraction followed by celite chromatography and radioimmunoassay. C was not significantly different between the three groups (30.77 ng/ml) and T levels were as follows, TI, 14.03 ng/ml, EI, 3.88 ng/ml, and CI, 0.88 ng/ml. Significant hypertrophy (51.2% difference in wet weight of experimental vs.control leg) occurred in the plantaris muscle in a 16 day period following the surgery. There were no significant differences in the extent of hypertrophy between the three groups. These results suggest that other factors within the muscle such as the constant extreme mechanical overload/stretch have an overwhelming influence and T plays a minimal role in this ablation model. It may be that T plays a larger anabolic role in the face of high C levels.

FAT METABOLISM

20.1

THE EFFECT OF CHOLINE AND MYO-INOSITOL ON LIVER AND CARCASS FAT LEVELS IN AEROBICALLY TRAINED RATS. James L. Kenney and Karen A. Carlberg. Eastern Washington University, Cheney, WA 99004

Choline and myo-inositol have been shown to prevent abnormal or excessive accumulation of cholesterol and triglycerides in the liver in choline and myo-inositol deficient rats. This study was designed to determine whether the consumption of myo-inositol and choline affects the percent liver and carcass fat of non-deficient aerobically exercised rats. The percent liver fat was determined by two different methods: a lipid extraction procedure (Leshner *et al.* 1972) and a prediction determined by the percent water content (Cox *et al.* 1984). The percent carcass fat was determined by these two methods and an index derived from the rat's length and weight (Lee, 1929). There was no significant difference in the percent carcass fat between the two groups. There was a significant difference in the percent liver fat between the two groups, with the experimental group having less fat. There was no significant difference between the amount of chow consumed by the two groups. A difference in weight gain, with the experimental group gaining less weight, approached significance. The difference in weight gain was a combination of fat weight and lean weight. There was a significant positive correlation between the Lee Index and the Cox prediction for the carcass fat analyses. The decreased percent liver fat is presumed to be caused by increased mobilization of fat out of the liver. This increased mobilization did not affect the percent carcass fat. These results do not support using myo-inositol and choline as supplements to reduce adipose tissue mass. It is unknown whether a reduction in liver fat is advantageous or detrimental to a person's health and well being.

20.2

THE IMPACT OF ANEROBIC TRAINING ON CHOLESTEROL IN COLLEGE FOOTBALL PLAYER J. A. Richardson, B. Fischbach*, M. Stevenson*, D. Mareck*, and L. Tentinger*. University of South Dakota, Vermillion, SD 57069.

The purpose of this investigation was to measure the impact of physical exercise within the context of football practice and game situations on changes in total cholesterol (T-chol). The procedure employed to assay the T-chol of the athletes was the standard testing technique proscribed by the Mannheim Reflotron™ (Boehringer Mannhein, 1985). The thirty subjects were all members of the same football team and were assessed in three three-day periods before, after pre-season practices, and at the end of the regular season. They ranged in age from 19 to 22 years (μ = 19.6, σ = 1.18), T-chol 1 [ψ] screening from 100 to 230 milligrams per deciliter [mg/dL] (μ = 149, σ = 33.6), T-chol 2 [β] screening from 100 to 208 mg/dL (μ = 138.3, σ = 32.1), and T-chol 3 [ψ] screening from 100 to 307 mg/dL (μ = 167, σ = 50.42).The correlations of α vs β was .676, α vs ψ was .735, and β vs ψ was .674. This supports the accuracy of the method of evaluating the α, β, and ψ. Further, there were significant differences between α, vs β (6.983), and ψ vs. β (3.461) at the 95% level using a two-tailed t-test. In addition, both Fisher (PLSD) and Scheffe (F-test) indicated significance between assay α vs ψ (PLSD = 12.078, and F-test = 4.451), and β vs ψ (PLSD = 12.078, and F-test = 11.288) at the 95% level. Even though the population used in this investigation was small (30 subjects), there are a few conclusions that can be drawn: 1. the frequency and intensity of the physical activity of the two-a-day practices may be of little or no physiological value in the control of T-chol in college age football players, 2. the duration and intensity of regular physical activity experienced during the season has a statically significant impact on T-chol levels in these subjects, 3. there appears to be a rebound of the level T-chol as suggested by the significance of the differences between β and ψ, and 4. regularity of physical activity reduced T-chol in college age football players.

20.3

EFFECT OF DIETARY MANIPULATION ON PHYSIOLOGICAL AND METABOLIC ADJUSTMENT TO MAXIMAL $\dot{V}O_2$ AND ENDURANCE IN TRAINED RUNNERS.
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Endurance athletes often consume a diet which is high in carbohydrates and low in fat. Many of the adaptations that occur in response to endurance training result in an increased capacity to utilize fat, up to 90% $\dot{V}O_2$max. The present study examined the effects of diet composition in six runners. The energy contributions from carbohydrate, fat and protein were 61/24/14, 50/38/12 and 73/15/12 for the normal (N), fat (F) and carbohydrate (C) diets, respectively. Expiratory and blood responses to a maximum ($\dot{V}O_2$max) and prolonged (75-85% $\dot{V}O_2$max) treadmill run were determined following seven days on each diet. Free fatty acids (FFA), triglycerides, glycerol, glucose and lactate were measured. Statistical evaluation was performed using ANOVA ($p \leq 0.05$); values are mean±SEM. Running time to exhaustion was greatest after F (91.2±9.5 min) compared to C (75.8±7.6 min) and N (69.3±7.2 min). $\dot{V}O_2$max was also higher on F (66.4±2.7 ml/kg/min) vs. C (59.6±2.8 ml/kg/min) and N (63.7±2.6 ml/kg/min). FFA were higher and glycerol was lower during F than C and N. Other biochemical measures did not differ significantly between diets. Elevated FFA on the F diet provided enhanced oxidative potential, as evidenced by an increased $\dot{V}O_2$max and running time. Severe restriction of dietary fat may be detrimental to endurance performance.
Supported by the Office of Naval Research.

20.4

THE IDENTIFICATION OF THE EXERCISE INTENSITY WHICH MAXIMIZES FAT OXIDATION.
Frank A. Kulling*, David Atkins and Bert H. Jacobson. Oklahoma State University, Stillwater, OK 74078.

The purpose of this study was to identify the exercise intensity (EI) which maximizes fat oxidation (FO) in young women and compare resultant heart rate (HR), respiratory quotient (RQ) and FO with an EI prescribed at 60% of functional capacity (FC). Ten untrained, apparently healthy women volunteered as subjects. Identifying characteristics included: Age 21.3 ± 4.6 yrs; Ht 162.2 ± 7.8 cm; Wt 61.9 ± 7.1 kg; body fat 18.7 ± 3.4% and FC 11.8 ± 1.3 METS. Each subject completed a maximal, modified Bruce treadmill test which permitted steady state attainment between stages. Expired gases were collected every 15 seconds and analyzed using a metabolic cart. HR and EKG were continuously monitored. The FO EI was determined by converting VO_2 and RQ to kcal fat/min using a lusk RQ table. FO EI for our sample was 50.4 ± 4.5% FC. Paired t tests depicted both HR (134.8 ± 8.9 vs 151.3 ± 10.2) and RQ (0.78 ± .04 vs 0.89 ± .06) to be significantly ($P<.01$) lower at FO EI. Relative FO (kcal/min) was slightly (4.4 ± 1.0 vs 3.2 ± 1.9) but insignificantly ($P>.05$) higher at FO EI. If each EI was continued to 300 kcal of total energy expenditure, FO EI would result in a projected doubling of total FO (195.6 ± 44.4 vs 97.9 ± 59.1 kcal). We conclude exercise at 50% FC will oxidize at least as much fat/min as higher intensities, and if continued to equalize total kcal expended will project a substantial increase in total FO.

20.5

POLYUNSATURATED DIETARY FAT REDUCES THE CHOLESTERYL ESTER (CE) TRANSITION TEMPERATURE (Tm) OF LOW DENSITY LIPOPROTEINS (LDL).
James M. Manning, Abraham Gebre,* Lawrence L. Rudel* and John S. Parks*. The Bowman Gray School of Medicine of Wake Forest University, Winston-Salem, NC 27157

Polyunsaturated dietary fat (n-3 and n-6) results in less atherosclerosis in monkeys compared to saturated (Sat) fat. We hypothesized that this result is due, in part, to a lower LDL Tm, which is indicative of the CE liquid crystalline to liquid transition. LDL was isolated from the plasma of cynomolgus monkeys fed either fish oil (FO)(n=6), monounsaturated (Mono)(n=6), n-6 polyunsaturated (Poly)(n=6) or saturated (Sat)(n=7) fat diets. The Tm (^{o}C) of individual LDL was determined by differential scanning calorimetry and the results were ordered: FO (35.5±1.3) = Poly (35.7±0.6) < Mono (39.9±0.6) = Sat (44.4±0.9). Plasma LDL cholesterol concentrations (mg/dL) were ordered: FO (365±45) = Sat (352±27) = Poly (279±24) > Mono (230±43). The percentage composition of LDL was similar among diet groups except that FO LDL were relatively depleted of cholesteryl ester [FO (52.0±0.8) < Mono (56.4±0.9) = Poly (56.9±0.5) = Sat (55.9±1.2)] and enriched in protein: FO (19.2±1.3) > Mono (15.9±1.9) = Poly (16.6±0.8) = Sat (15.8±1.1). We conclude that FO and Poly dietary fat result in LDL that have liquid CE cores at body temperature compared to those of the Sat and Mono diet groups that were liquid-crystalline. These data suggest that n-3 and n-6 polyunsaturated dietary fat may have decreased atherosclerosis in previous studies, in part, by lowering the LDL transition temperature.

20.6

LONG TERM RESISTIVE (WEIGHT) TRAINING EFFECTS ON PLASMA LIPOPROTEIN IN THE PREMENOPAUSAL FEMALE.
W. Ensign, T.G. Lohman, and S.B. Going* University of Arizona, Tucson, Arizona 85721.

The ability of resistive training to alter plasma lipoprotein and lipid metabolism in the premenopausal female remains unclear. The goal of this investigation was to evaluate the effects of long term weight training on plasma lipoprotein in this population. 104 previously untrained, eumenorrheic females (28-40 years) were randomly assigned to an Experimental (n=56) and a control group (n=48). The E group lifted weights (under supervision) 3 days/wk. for 18 months. Both E and C had body composition, plasma lipoprotein and triglyceride levels analyzed at baseline, 5 months, 12 months, and 18 months. Dietary intake was also monitored. Complete data were collected on 48 females (E,n=20, C,n=28). During the study period over 18 months, total cholesterol was reduced in both E and C; this reduction was significantly greater in E then C (5.87mM/L($\bar{x}$) ± -0.96 (SD), 5.56mM/L ± -0.79 vs. 4.65mM/L ± -0.94, 4.89mM/L ± -0.90, $P < .03$). Over the 18-month period, total high density lipoprotein cholesterol (HDL-C) remained unchanged in E (1.29mM/L ± -0.40 vs. 1.22mM/L ± -0.26) but was reduced in C (1.58mM/L ± -0.45 vs. 1.32mM/L ± -0.28, $P < .00$). Analysis of the HDL-C subfractions indicated no significant changes in HDL-C_3 in either E or C. HDL-C_2 increased 31% in E (0.26mM/L ± -0.20 vs. 0.34mM/L ± -0.12, $P < .02$) and was unchanged in C (0.42mM/L ± -0.25 vs. 0.36mM/L ± -0.15). A reduction in low density lipoprotein cholesterol (LDL-C) occurred in both E and C, but was greater in E vs. C after 18 months of training (4.23mM/L ± -0.94, 3.62mM/L ± -0.78 vs. 3.05mM/L ± -0.88, 3.04mM/L ± -1.02, $P < .03$). No significant changes in triglyceride were observed. We conclude that long-term resistive training can alter plasma cholesterol levels in the premenopausal female with little effect on plasma triglycerides.

20.7

DECREASE IN MUSCLE MALONYL-CoA UNAFFECTED BY ADRENODEMEDULLATION.
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Malonyl-CoA is an inhibitor of carnitine palmitoyl transferase, a rate limiting enzyme of fatty acid oxidation. Previous studies have indicated that muscle malonyl-CoA declines in rats during treadmill running. This decrease may be important for allowing an increased rate of fatty acid oxidation during prolonged submaximal exercise. This study was designed to determine if epinephrine is essential for inducing the decline in muscle malonyl-CoA during exercise. Male Sprague-Dawley rats were adrenodemedullated (ADM) or sham operated (SO). After allowing 3 wks for recovery, rats (fed *ad libitum*) were killed at rest or after running at 21 m/min up a 15% grade for 60 min. Rats were anesthetized by intravenous injection of sodium pentobarbital. Red and white regions of the quadriceps muscle were quick frozen in liquid nitrogen and later analyzed for malonyl-CoA. Red quadriceps malonyl-CoA decreased from 2.6 ± 0.3 to 0.8 ± 0.07 nmoles/g in SO and from 2.2 ± 0.3 to 0.7 ± 0.1 nmoles/g in ADM (n = 10-12). White quadriceps malonyl-CoA decreased to similar levels (0.11 ± 0.03 nmoles/g) during exercise in both ADM and SO rats. The hormones of the adrenal medulla are therefore unessential for inducing the exercise-induced decline in muscle malonyl-CoA. (NIH DK40448 and AR41438)

20.8

FATTY ACID SPARING OF PYRUVATE IN ISOLATED SKELETAL MUSCLE MITOCHONDRIA: EFFECTS OF ATP DEMAND AND MITOCHONDRIAL CONTENT
Matthew R. Jackman*, Casey M. Donovan, and Wayne T. Willis
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The purpose of this study was to measure pyruvate utilization by isolated muscle mitochondria with and without fatty acids as an alternative fuel. The effects of differing levels of ATP demand and mitochondrial content of the in vitro system were also studied. Mitochondria were isolated from rat hindlimb muscle and respired in KCl based buffer containing 2 mM ATP and 20 mM glucose. The substrate supply included 0.6 mM pyruvate + 1 mM malate in all incubations. Experiments examining fat sparing of pyruvate contained 7.5-22.5 uM palmitoyl-l-carnitine. O_2 consumption was varied from state 4 to various percentages of state 3 with hexokinase. Respiration was terminated in $HClO_4$ and neutralized extracts were analyzed for ATP, ADP, and G6P. Results indicated that (1) the addition of palmitoyl-l-carnitine spared a nearly constant absolute amount of pyruvate regardless of ATP demand, (2) thus, relative sparing of pyruvate was greater at lower rates of ATP demand, (3) at a given rate of ATP demand, increasing the mitochondrial content increased the amount of pyruvate spared. The data indicate that fatty acids spare pyruvate at the mitochondrial level, and that greater relative sparing occurs at lower ATP demand and with greater mitochondrial contents.

21.1

EFFECT ON ENDURANCE PERFORMANCE OF ADDING POLYLACTATE TO A GLUCOSE POLYMER SOLUTION. Thomas Swensen*, G. Craytor*, and E.T. Howley. University of Tennessee, Knoxville, TN. 37996

Four highly trained male cyclists (mean VO_{2max} = 71 ml·min^{-1}· kg^{-1}) volunteered to perform two endurance trials each until exhaustion at 70% of their VO_{2max} on a modified Monark ergometer. In a double blind and random crossover design, the athletes consumed either an artificially sweetened and flavored glucose polymer solution (GP) or a similarly sweetened and flavored glucose polymer/polylactate (GP/PL) mixture at a rate of .3 grams carbohydrate per kg of body weight every 20 min in a 7% solution. As determined from pilot work, the maximum tolerable GP/PL mixture was approximately 9 parts GP and 1 part polylactate (PL). There was no difference in time to exhaustion between the trials, as the athletes rode for 198±35 min when they drank the GP solution versus 199±43 min when they drank the GP/PL solution. Moreover, there was also no difference in the respiratory exchange ratio, ratings of perceived exertion, blood lactate, blood pH, and serum glucose between the trials. Based on these data, we conclude that adding PL to a GP solution had no effect on endurance performance.

This work received support from the Cycling Science Association, Champion Nutrition, Ross Laboratories, Kodak Chemicals, and the University of Tennessee's Department of Zoology and Life Sciences Program.

21.2

EFFECTS OF HEPATIC PORTAL PYRUVATE INFUSION ON HORMONAL RESPONSE IN EXERCISING RATS. S. Cardin*, R. Hélie*, B. Compte*, G. van de Werve*, and J.-M. Lavoie, Department of Physical Education and Nutrition, Univ. of Montréal, Montréal, Canada.

It has been recently reported that a vagotomy of the hepatic vagus branch can modulate the hormonal response in adrenodemedullated exercising rats. One of the hypothesis that has been put forward to explain this observation is that the hepatic pyruvate concentration can influence the firing rates of the hepatic vagus branch during exercise. The purpose of this study was to investigate the effects of a hepatic portal pyruvate infusion (0.016 ml/min, 5% p/v) on the hormonal responses to a 30-min treadmill run (26 m/min, 0% grade) in adrenodemedullated rats. The pyruvate infusion during exercise was associated with a smaller decrease in plasma insulin concentrations and with a smaller increase in glucagon concentration. The exercise increase of norepinephrine concentrations was also attenuated in hepatic portal pyruvate infused group. These results suggest that the hepatic pyruvate concentration can play a role in the regulation of the hormonal response in exercising adrenodemedullated rats.

Grant: NSERC and FCAR

21.3

INFLUENCE OF SODIUM ON GLUCOSE BIOAVAILABILITY DURING EXERCISE. **M. Hargreaves, D. Costill, L. Burke, M. Febbraio and G. McConell, Department of Physiology, The University of Melbourne, Parkville and Exercise Metabolism Unit, Victoria University of Technology, Footscray, Australia.**

To examine the influence of beverage sodium content on glucose bioavailability during exercise, six trained men (21.7 ± 1.0 yrs, 67.1 ± 2.3 kg, $\dot{V}O_2$ max = 4.20 ± 0.14 l.min^{-1}, mean ± SE) were studied during 30 min of cycle ergometer exercise at a workload estimated to require 65% $\dot{V}O_2$ max. Immediately prior to exercise, subjects ingested 400 ml of a 10% glucose solution containing 100 µCi of D-[3-^{3}H]-glucose, with a sodium concentration of either 0, 25 or 50 mmol.l^{-1}. Trials were conducted in the morning after an overnight fast and in randomized order at least one week apart. Blood samples were obtained from a forearm vein before exercise and after 5, 10, 20 and 30 min of exercise. These were subsequently analyzed for plasma glucose and ^{3}H-glucose radioactivity and blood lactate. No differences were observed between trials for oxygen uptake, heart rate or blood lactate during exercise. Resting plasma glucose levels were not different between trials (0: 4.4 ± 0.2 mmol.l^{-1}; 25: 4.5 ± 0.3; 50: 4.4 ± 0.3, P>0.05). The increase in plasma glucose and the plasma accumulation of ^{3}H-glucose were similar in the three trials. Plasma glucose levels peaked after 20 min of exercise and were not different between trials (0: 6.2 ± 0.4 mmol.l^{-1}; 25: 6.1 ± 0.3; 50: 6.2 ± 0.4, P>0.05). After 30 min of exercise, the plasma ^{3}H-glucose activity was similar in the three trials (0: 3518 ± 282 dpm.ml^{-1}; 25: 3482 ± 443; 50: 3860 ± 458, P>0.05). The results of the present study indicate that alterations in beverage sodium content have no effect on glucose bioavailability during exercise.

This study was supported by Ross Australia.

21.4

EFFECT OF DIFFERENT STIMULATION STRATEGIES ON GLUCOSE UPTAKE IN RAT MUSCLES E.Jóhannsson *, J.Jensen * and H.A.Dahl. Dept. of Anatomy, Inst. of Basic Med. Sci., Univ. of Oslo, and The Norw. Univ. of Phys. Ed. and Sport, Oslo, Norway.

The aim of this study was to investigate the effect of different stimulation strategies on glucose uptake (GU) in soleus (SOL) and gastrocnemius (GAST) muscles. The stimulated GU (SGU) was measured with the ^{3}H-DG-method and reported as mmol.kg^{-1}.20 min^{-1}. The muscles were stimulated 20 min. through the sciatic nerve. 100 Hz trains of 200 msec. duration were given every 400 msec. (100-High) or 2 sec. (100-Low), and 20 Hz trains of 10 sec. duration every 20 sec. (20-High) or 60 sec. (20-Low). In SOL the higher SGU was obtained in 100-High ($p<0.01$), in GAST in 20-High ($p<0.05$).

	100-High	100-Low	20-High	20-Low
SOL	3.1 ± 0.5	0.6 ± 0.6	1.2 ± 0.1	0.2 ± 0.2
GAST	3.1 ± 1.2	1.7 ± 1.0	6.1 ± 2.3	2.1 ± 1.7

This means that the higher SGU is obtained by different stimulation regimes in SOL and GAST, and that the stimulation frequency and duration of the impulse trains are important for the magnitude of SGU.

21.5

UTILIZATION OF INGESTED GLUCOSE DURING A 4-HR WALK. C.Pitre[1*], D. Massicotte[1], F. Péronnet[2], G.R. Brisson[3], and C. Hillaire-Marcel[1*], Université du Québec à Montréal[1], Université de Montréal[2], INRS-Santé[3], Montréal, Canada, H3C 3P8.

Taking into account the "background effect" with an ^{13}C-isotopic tracer, the purpose of this study was to measure the oxidation rate of 100 g of glucose (diluted in water, 25%) ingested at the beginning of a 4- hr exercise. Six healthy young males (22.0 ± .6 yrs; $\dot{V}O_2$max = 55.6 ± 3.2 ml/kg.min) performed three exercises (2 with glucose and 1 with water ingestion) on a treadmill at 50 ± 2.5% $\dot{V}O_2$max (5.5 - 6.2 km/hr, 10% slope). In order to correct for the "background effect" due to exercise and/or to substrate ingestion as detailled by Péronnet et al. (JAP 69: 1047-1052, 1990), two levels of ^{13}C - glucose enrichment were used: -11.3 (GN) and + 189.7 (GE) $^0/_{00}$ δ ^{13}C/PDB. Over the 4-hr period of exercise, 78.2 ± 3.9 g of exogenous glucose were oxidized when the "background effects" were considered (computation with GN and GE), compared to 108.6 ± 30.9 or 104.7 ± 34.3 g without this correction. In these last cases (conventional computation procedure using GN and resting or exercise with water ingestion), the oxidation rates exceeded the amounts ingested and the results were overestimated by more than 35%. Due to the magnitude of the isotopic signal when GE is ingested, the oxidation rate may also be computed by the difference of $V^{13}CO_2$ produced between GE and rest (82.9 ± 4.2 g) or GE and exercise with water (82.1 ± 3.1 g). In conclusion, the use of ^{13}C - isotope tracer to evaluate the oxidation rate of exogenous carbohydrates requires either two levels or a high level of ^{13}C- enrichment in order to correct the "background effect". The longer is the exercise, the greater is the overestimation of the results. (Supported by NSERC, Canada).

21.6

REGULATION OF GLUCOSE FLUXES DURING EXERCISE IN HEALTHY MALE SUBJECTS. C. Lavoie and J.L. Chiasson. Research Group on Diabetes and Metabolic Regulation, IRCM and McGill University, Montréal (Québec), H2W 1R7 (Funding by Diabetes Canada)

Using a stable isotope technique, we have further characterized the regulation of glucose fluxes in healthy subjects during a 2-hour exercise at 40% VO_2 max. Somatostatine (SRIF) was used to inhibit endogenous production of insulin and glucagon. During exercise, **plasma glucose** levels fell from 4.5 mmol/L to 4.3, 3.7 and 3.8 in the control, the SRIF and the SRIF + insulin groups, but increased to above 6.0 mmol/L during SRIF + glucagon infusion. Exercise increased **hepatic glucose production** from 12.1 ± 0.2 to 28 ± 1.4 µmol/kg.min in the control, to 13.0 ± 1.2 in SRIF, 17.0 ± 1.0 in SRIF + insulin and to 36.0 ± 1.6 in SRIF + glucagon. Muscle contractions increased **glucose utilization** in the 4 protocols and paralleled very closely glucose production. During muscle contractions, basal **metabolic glucose clearance** (2.68 ± 0.04 ml/kg.min) increased to 6.9 ± 0.3 in the controls, 4.8 ± 0.3 in the SRIF, 6.9 ± 0.2 in the SRIF + insulin, and to 5.4 ± 0.2 in the SRIF + glucagon group. **Gluconeogenesis** increased during exercise from 0.67 ± 0.02 to 0.96 ± 0.06 µmol/kg.min in the control, to 0.49 ± 0.03 in the SRIF, to 0.59 ± 0.05 in SRIF + insulin and to 1.5 ± 0.1 in SRIF + glucagon. **Glycerol** as an index of **lipolysis** increased in all protocols (.036 ± .004 to .178 ± .018 mmol/L) independently of the pancreatic hormones. **In conclusion,** these data suggest that during mild-moderate exercise in healthy male subject: 1) the increase in hepatic glucose production is essentially dependent on glucagon; and 2) the glucose uptake by the contracting muscle is dependent a) of muscle contraction per se, and b) of circulating insulin.

21.7

CARBOHYDRATE FEEDING FOLLOWING CARBOHYDRATE LOADING ENHANCES PROLONGED EXERCISE PERFORMANCE

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This investigation determined whether carbohydrate (CHO) feeding during prolonged strenuous exercise enhances endurance following pre-trial CHO loading. Eight male cyclists performed two cycle trials to fatigue at a power output corresponding to 70% VO2peak. During the trials, subjects ingested either a 6% glucose/sucrose (GS) solution at the rate of 0.6 $g.kg(BW)^{-1}.h^{-1}$ or an equal volume of placebo (P) every 20 min throughout exercise. The two trials were preceded by a standard CHO depletion-loading procedure. Time to fatigue (min) was longer ($P<0.05$) in GS than P (197±26.9 vs. 157±15.6). Blood glucose (mM) did not differ between the trials prior to (4.94±0.16 vs. 4.88±0.19) and after 20 min of exercise (4.92±0.19 vs. 5.04±0.15), but was higher at fatigue ($P<0.05$) in GS than P (4.73±0.20 vs. 3.98±0.18). Blood glucose did not decline during GS but decreased ($p<0.05$) during P from pre-exercise to termination. Blood glycerol (mM) did not differ between trials prior to (0.15±0.03 vs. 0.15±0.02), after 20 min of exercise (0.24±0.04 vs. 0.23±0.04), and at fatigue (0.42±0.05 vs. 0.48±0.06). Glycerol increased ($p<0.05$) from pre-exercise to termination during GS and P. RER did not differ between trials after 20 min of exercise (0.93±0.01 vs. 0.93±0.01) and at fatigue (0.86±0.01 vs. 0.83±0.01). RER decreased ($p<0.05$) during GS and P. The estimated total glucose oxidation (g) was higher ($p<0.05$) in GS than P (481.02±45.67 vs. 373.96±30.20). RPE (Borg-15 pt scale) for legs, chest, and overall did not differ between trials after 20 min of exercise (13.0±0.9 vs 12.0±0.7, 10.1±0.8 vs. 9.6±0.8, and 11.2±0.8 vs. 11.0±0.5, respectively) and at fatigue (18.5±0.5 vs. 17.9±0.4, 13.6±1.2 vs. 13.6±1.1, and 16.5±0.8 vs. 16.4±0.8, respectively). RPE (legs, chest, overall) increased ($p<0.05$) during GS and P. It is concluded that CHO feeding subsequent to CHO loading can prolong endurance performance owing to enhanced CHO oxidation.

(Supported by student research grants from the Quaker Oats Company and the School of Education, University of Pittsburgh)

21.8

THE EFFECT OF INTRALIPID® INFUSION AND FAT FEEDING ON MUSCLE GLYCOGEN UTILIZATION DURING EXERCISE.

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Five healthy men completed three 60min of cycle ergometer trials (EX) at 70% VO2max. Fatty acids were elevated by a fat feeding (FF) consisting mostly of saturated fatty acids (cream) (50 g), or by the infusion of Intralipid® (IL) (Clintec Nutrition Co.) (45 ml/hr of 20% Intralipid®, 9.0g) which is 85% unsaturated. A control trial (CON) consisted of a light breakfast (43g CHO/1g fat). Heparin was administered (2000 units) 15min before EX in FF and IL trials only. Expired air was collected during EX by Douglas bags every 15min, and VO2, RER, kilocalories (KCAL), and grams of fat and CHO (GFAT, GCHO) oxidized were calculated. Blood samples were taken pre- treatment, preheparin, 00,15,30,45,& 60 min of EX and analyzed for FFA, TG, glycerol, glucose. Muscle biopsy samples were taken pre- and post- exercise and analyzed for glycogen. Preexercise muscle glycogens were not different. The utilization of muscle glycogen was less ($p<0.05$) during FF(60.2±6.23 mmol/kg) and IL(59.2±7.53 mmol/kg) compared to CON (83.5±9.08mmol/kg) during the 60min of EX. There was no difference between FF and IL in the amount of glycogen utilized. TG were greater ($p<0.05$) at preheparin in FF(1.5± 0.30 mmol) and IL(1.0±0.13 mmol) compared to CON (0.47±0.14mmol). FFA were increased ($p<0.05$) in FF and IL following heparin administration and were greater ($p<0.05$) than CON. However, FFA in FF were greater ($p<0.05$) than both IL and CON at 00, 15, & 30min of exercise. FFA in IL were only greater ($p<0.05$) than CON at 00 of EX. There were no differences in VO2, RER, HR, KCAL, GFAT, and GCHO among the three trials. These results suggest that increasing FFA will spare glycogen, with no difference regarding the type or source of TG. In addition, the sparing of muscle glycogen was not dependent on the concentration of FFA.

21.9

ENHANCED FFA AVAILABILITY DECREASES MUSCLE GLYCOGENOLYSIS DURING INTENSE AEROBIC CYCLING.

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Six male subjects of varied training status cycled at 85% VO_2 max for 15 min on two occasions to examine the effect of enhanced free fatty acid (FFA) availability on muscle glycogenolysis. An Intralipid/heparin (INT) or saline (CON) solution was infused in two randomized trials. Muscle biopsies were sampled pre and post exercise. O_2 uptake (CON, 85.1 ± 2.8%; INT, 84.9 ± 2.0%) and RER (CON, 0.84 ± 0.01; INT, 0.84 ± 0.02) were similar between trials. Plasma [FFA] were unchanged during 30 min of rest (0.16 ± 0.04 to 0.18 ± 0.06 mM) and exercise (0.15 ± 0.03 to 0.11 ± 0.03 mM) in the CON trial. The INT infusion increased resting [FFA] from 0.22 ± 0.04 mM at -30 min to 0.94 ± 0.08 mM at 0 min and to 1.27 ± 0.14 and 1.41 ± 0.12 mM at 5 and 15 min of cycling. Plasma [glycerol] was 4-7 fold higher in the INT trial and whole blood glucose and lactate were similar between trials. Resting muscle glycogen in the CON and INT trials was 427.0 ± 77.7 and 468.4 ± 84.3 mmol/kg dm (range, 246-727 mmol/kg dm). Glycogenolysis was reduced in all subjects during the INT trial (CON, 172.6 ± 24.6 and INT, 110.3 ± 24.7 mmol/kg dm; $p<0.01$). In summary, increased FFA availability decreases muscle glycogenolysis during the initial 15 min of intense cycling. This finding was independent of training status and pre-exercise glycogen content.

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21.10

CONTRIBUTION OF GLUCONEOGENESIS TO GLUCOSE HOMEOSTASIS WITH AGING: INFLUENCE OF TRAINING.

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The capacity for glucose homeostasis is well-known to decline with advancing age. This study investigated the influence of both aging and training on hepatic gluconeogenesis in rats. Training consisted of ten weeks of treadmill running at 75% maximal capacity, one hr/day, five days/wk. One-half of 30 trained (TR) and 33 untrained (UN) male Fischer 344 rats, initial ages of 4, 12, and 22 months, were injected with a known gluconeogenic inhibitor, 3-mercaptopicolinic acid (MPA). Two endurance tests were performed to help assess the contribution of gluconeogenesis to exercise performance, an initial test four days prior to injection and a final test post-injection (300 mg/kg). MPA significantly ($p<0.05$) reduced running performance in all TR groups compared to the control test: 89%, 81% and 51% in the young, middle aged and old, respectively. MPA reduced running times in the untrained 19%, 11% and 8%. Blood glucose levels were significantly lower prior to running with MPA treatment vs control across all age groups (4.5 vs 8.3 mM). Running further suppressed glucose levels in the MPA animals (↓24 & 10% for TR and UN, respectively) while no difference existed in the controls. Incubation of liver slices with ^{14}C-lactic acid demonstrated a significant decline in incorporation of tracer into glycogen with age (18248, 5692, and 3363 dpm/g in young, middle and old, respectively). Training resulted in a 38% increase in glycogenesis from lactate in young animals, however, no significant differences were observed for middle and old groups. It was concluded that hepatic gluconeogenesis is impaired with age and endurance training has a minimal effect in off-setting this response.

21.11

EFFECT OF PRE-EXERCISE DIET ON MUSCLE GLYCOGEN UTILIZATION AND FORMATION OF ACETYLCOA AND ACETYLCARNITINE DURING EXERCISE IN MAN

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We examined the relationship between substrate supply and the formation of acetylCoA (AcCoA) and acetylcarnitine (AcCAR) in skeletal muscle during exercise. Five trained young males (mean±SD: VO_2max 61.1±6.09 ml kg^{-1} min^{-1}; age 22.8±1.94 yrs) cycled at 75% VO_2max to exhaustion (EX) after several days on a carbohydrate-free diet (CFD) and subsequently for the same duration (end exercise:EE) after several days on a high carbohydrate diet (HCD). Muscle biopsies were taken from the vastus lateralis at rest (R), 16 min exercise (T16), EX and EE. Glycogen utilization was lower ($p=.001$) after CFD (R to EX mean±SEM: 3.6±0.62 mmol/kg dm/min) than after HCD (R to EE: 9.5±0.96 mmol/kg dm/min). During exercise, the AcCoA concentration decreased after CFD (AcCoA R to EX µmol/kg dm: R 39.3±7.66; T16 17.2±1.53, $p=.005$; EX 16.2±1.58, $p=.005$) and increased after HCD (µmol/kg dm: R 13.5±1.88; T16 32.2±2.02,$p=.05$; 37.6±2.67,$p=.01$). Changes in AcCAR content paralleled those of AcCoA, decreasing after CFD (mmol/kg dm: R 11.1±1.02; T16 8.8±0.70, $p=.06$; EX 6.9±1.21, $p=.005$) and increasing after HCD (mmol/kg dm: R 2.5±0.81; T16 12.1±0.87, $p=.0002$; EE 12.5±0.71, $p=.0002$). The difference in acetyl group accumulation seems to be related to substrate utilization differences after CFD and HCD. Greater fat availability at R after CFD increased AcCoA accumulation from β-oxidation which decreased PDHa transformation (CFD vs HCD mmol/kg dm/min: 0.82±0.15 vs 2.81±0.18, $p=.003$) limiting further AcCoA formation from pyruvate. In exercise (CFD) the formation of acetyl groups is lower than the amount oxidized due to an insufficient rate of β-oxidation and a reduction in pyruvate availability (CFD vs HCD mmol/kg dm: T16 0.52±0.06 vs 0.80±0.09, $p=0.3$; EX/EE 0.62±0.06 vs 0.86±0.14, $p=0.06$). During exercise after HCD, acetyl group accumulation seems to be related to the greater availability of glycogen and pyruvate, and dependent on greater PDHa (CFD vs HCD mmol/kg dm/min:T16 6.61±0.99 vs 11.83±1.14, $p=.04$; EX/EE 8.42±0.82 vs 14.41±0.75, $p=0.002$), resulting in acetyl group formation from glycogen which is greater than its utilization. These data suggest that AcCoA and AcCAR accumulation during exercise are dependent on substrate availability and are related to PDHa.

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21.12

Effects of training and testosterone on muscle glycogen content in non-insulin-dependent diabetes mellitus female rats.

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In this study the effect of testosterone (T) on glycogen content in soleus and extensor digitorum longus (EDL) muscle was studied in 6 groups of adult non-insulin dependent diabetes mellitus (NIDDM)(by neonatal streptozotocin 100 mg/kg BW) female Brown-Norway rats. Two groups of rats remained sedentary, whereas the others were trained for 7 weeks. Thereafter the rats were divided into control and T-treated (by means of 4 mm silastic tubes) groups. Thereafter training was continued for an additional 2 weeks. On the experimental day the animals were killed by cervical dislocation and blood and tissue were sampled. Results on plasma T level and glycogen (mean ± SD for n=6) were:

Group	Plasma T (nmol/l)	glycogen (µmol/g dw) soleus	EDL
sedentary	0.9 (±0.2)	48.9 (±15.1)	113.3 (±12.1)
sedentary + T	5.7 (±1.6)*†	69.5 (± 7.4)*	105.3 (± 8.5)
NIDDM sedentary control	0.9 (±0.2)	38.5 (± 4.7)*	104.4 (± 5.9)*
NIDDM sedentary + T	4.9 (±1.3)*†	70.7 (±16.3)* †	122.9 (± 7.5)*†
NIDDM trained control	1.0 (±0.1)	64.9 (±11.1)*	116.3 (± 5.9)
NIDDM trained + T	4.8 (±1.5)*†	75.5 (±12.9)* †	124.3 (± 4.9)*†

Significantly different (Anova) from sedentary (*) or from trained control (†).

We conclude that in skeletal muscle of female rats: (1) Glycogen content is decreased in NIDDM rats; (2) T increases glycogen content in sedentary soleus but not in EDL muscle; (3) training and T treatment each increase the glycogen content of NIDDM soleus muscle; (4) T but not training increases glycogen content in NIDDM EDL muscle. These data suggest that training with or without T treatment in NIDDM animals, increase muscle glycogen content.

21.13

GLUCOSE UPTAKE DURING EXERCISE IS IMPROVED BY INDIRECT EFFECTS OF INSULIN. Z. Shi*, A. Giacca*, K. YAMATANI*, S. Fisher*, L. Lickley* and M. Vranic, Univ. of Toronto, Canada, M5S 1A8

We wished to determine whether insulin's effects on glucose utilization during exercise can be reproduced by reduced provision of energy from free fatty acids (FFA). The effects of a subbasal dose of insulin (SI, 50 μU/kg/min, i.v.), methylpalmoxirate (MP, inhibitor of FFA oxidation, 20 mg/kg/day, 2.5 days), MP+SI and MP+P (propranolol, inhibitor of lipolysis, 5 μg/kg/min, i.v.) on glucose metabolism were studied in depancreatized, 24 h insulin-deprived dogs at rest and during exercise (6 km/h, 10% slope, n=6 for each protocol). At rest, SI reduced plasma glucose (PG, 13%, p<0.01) and increased glucose utilization (GU, 86%, p<0.001) and clearance (MCR, 72%, p<0.001). MP lowered PG (15%) and decreased glucose production (Ra, 25%, both p<0.05), but had no effect on GU. MP+SI decreased PG by 44%, due to reduced Ra (50%) and increased GU and MCR (29% and 128%, p<0.01). SI or MP did not affect GU or MCR during exercise. MP+SI and MP+P elevated the exercise-induced rise in MCR (2X and 1.5X), and decreased PG (20% and 13%, p<0.01) respectively. MP+P normalized the exercise-induced rise in GU. A highly significant inverse correlation existed between plasma glucose and the exercise-induced increase in MCR (r=-0.86, p<0.01). In summary: 1) Subbasal insulin alone improved GU and MCR only at rest; 2) A combined suppression of lipolysis and FFA oxidation markedly improved GU and MCR during exercise; 3) Combination of subbasal insulin and inhibition of FFA oxidation improved MCR during exercise; and 4) Improvement in MCR was correlated with correction of hyperglycemia. We conclude that insulin's effects in enhancing glucose utilization can be mediated, at least partially, by indirect mechanisms including suppression of lipolysis and correction of hyperglycemia.

21.14

GLUCOSE TOLERANCE AND INSULIN RESPONSE FOLLOWING EXERCISE: INFLUENCE OF MUSCLE MASS AND ABSOLUTE WORK. J.K. Brambrink, M.S. Hickey, J.D. Fluckey*, B.W. Craig, Human Performance Laboratory, Ball State University, Muncie, IN 47306.

To determine the influence of muscle mass and absolute work on glucose tolerance and insulin response following exercise, 12 subjects (26±1yrs; Two-leg VO_2max=3.0±0.3; One-leg VO_2max=2.3±0.2) were given an oral glucose tolerance test (OGTT) before and 16-18 hrs after 3 cycle ergometer exercise trials: 1) two-leg (TL) exercise, 60 % of the two-leg VO_2max, 2) one-leg (OL) exercise, 60% of the one-leg VO_2max, and 3) a one-leg (OLW) exercise, 60% of the one-leg VO_2max with total work matched to the two-leg trial. Each trial was preceded by two days of inactivity and a three day diet replication. Glucose tolerance was unaffected by either the amount of active tissue incorporated in the exercise and/or the amount of work completed by the active tissue. However, the insulin sums for the OGTT curve for the TL trial was significantly lower (p<0.05) than that of the OL trial following exercise, 266.05± 41.6 vs 347.62±37.6 uU/ml. This constituted a 23.5% decrease which was nearly matched by a 19% insulin decline when the total work of the TL trial was completed with one leg (OLW trial). Therefore, the results of this study indicate that both muscle mass and absolute work are important components in maintaining insulin responsiveness following exercise.

21.15

PROGRESSIVE RESISTANCE EXERCISE INCREASES INSULIN UTILIZATION WITHOUT IMPROVING GLUCOSE TOLERANCE IN NORMAL AND NONINSULIN-DEPENDENT DIABETIC INDIVIDUALS. James D. Fluckey*, Matthew S. Hickey, Jill K. Brambrink, Joseph F. Russo*, Kevin K. Hart* and Bruce W. Craig. Human Performance Laboratory, Ball State University, Muncie, IN 47306

Recent studies have demonstrated improvements in glucose tolerance following a single bout of aerobic exercise in both normal and noninsulin-dependent diabetic subjects. This study was conducted to determine if similar improvements in glucose tolerance would be observed following a nonaerobic form of exercise. Fourteen individuals, not currently weight training, were assigned to two groups based on the results of a 75 g (~1.2M) load oral glucose tolerance test (OGTT). Blood samples were collected through a 22 gauge Aquavene® catheter attached to a three way stopcock in an antecubital vein and assayed for glucose, insulin, and C-peptide. Patency was maintained by simultaneous saline infusion. The NIDDM group (n=7) consisted of adult individuals (50.7±1.85 yrs; x±SEM), with a mean resting blood glucose concentration of 7.87±0.85 mM and a maximum concentration of 13.98±1.27 mM (90 min sample) during the baseline OGTT. The CONtrol group (n=7) consisted of college-aged individuals (27.1±1.24 yrs), with a mean resting glucose concentration of 4.68±0.17 mM and a maximum concentration of 6.63±0.35 mM (30 min sample). Each subject participated in familiarization and 1RM exercise sessions using seven different Nautilus selectorized machines that utilized both the upper and lower body. After a 48 hr rest period, a 3 set x 10 repetition protocol based on the 1RM was completed by each participant. Eighteen hours following the lifting protocol, another OGTT was administered. Diets were recorded for two days prior to the baseline OGTT and duplicated for two days prior to the postprotocol OGTT. Analysis of variance failed to demonstrate significant differences in the total response to the glucose challenge from pre to postprotocol for glucose (p=0.53) or the C-peptide:insulin ratio (p=0.16) in either group. The C-peptide total response to the OGTT increased from 6.27 to 8.17 units (of area) from pre to postprotocol and did approach significance (p=0.07). The total blood insulin response to the OGTT was reduced by 24% and 22% for the NIDDM and CON groups, respectively (p<0.001). These results demonstrate that an acute bout of progressive resistance exercises increases insulin utilization without augmenting glucose disposal.

21.16

TRANSCRIPTIONAL REGULATION OF THE GLUT4 GLUCOSE TRANSPORTER GENE IN SKELETAL MUSCLE: EFFECTS OF DIABETES, FASTING, AND EXERCISE TRAINING. P.D.Neufer*, J.O. Carey* and G.L. Dohm, East Carolina Univ., Greenville, NC 27858

To determine whether expression of the glucose transporter protein GLUT4 may be regulated at the level of gene transcription, mRNA and nuclear run-on analysis was performed on nuclei isolated from skeletal muscle of Sprague Dawley rats under the following metabolic conditions: 1) diabetic (0.75 mg/kg streptozotocin), 2) fasted (3 days), or 3) exercise trained (1 wk). Diabetes significantly (P<0.05) reduced GLUT4 mRNA in both red (64%) and white (36%) quadriceps muscle as compared with controls. Likewise, transcription of the GLUT4 gene tended to decrease with diabetes in both red (17%) and white (26%) skeletal muscle (pooled quadriceps/gastrocnemius). Conversely, fasting significantly increased both GLUT4 transcription (1.7 fold) and mRNA (2.8 fold) content in white but not red skeletal muscle. Exercise training however failed to show any significant change in GLUT4 transcription in nuclei isolated from whole gastrocnemius muscle. Our findings demonstrate that expression of the glucose transporter GLUT4 in skeletal muscle is regulated at least in part at the level of transcription of the GLUT4 gene.

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21.17

GLUCOSE TRANSPORT ACTIVITY AFTER EXERCISE IN YOUNG, ADULT, AND OLD RATS. G.D. Cartee, C.A. Briggs-Tung*, and E.W. Kietzke*. Univ. of Wisconsin, Madison, WI 53706.

Young rats have an increase in muscle insulin-stimulated glucose transport for many hours after exercise. Our purpose was to determine if adult (12 mo) and old (24 mo) rats respond to exercise like young (3 mo) rats. We evaluated glucose transport using [^{3}H]-3-methylglucose (3-MG) in isolated epitrochlearis muscles. Values are expressed as μmol 3-MG accumulated/ml intracellular H_2O in 12 min. The 3-MG transport rate was unchanged in the absence of insulin 3.5 hr post-exercise. With 100 μU/ml insulin, 3-MG transport rate was elevated (p<0.05) 3.5 hr post-exercise in the young (0.49 vs. 0.86), adult (0.38 vs. 0.59), and old (0.29 vs. 0.49) rats. With 20,000 μU/ml insulin, 3-MG transport was elevated (p<0.05) 3.5 hr post-exercise in the young (0.89 vs. 1.20), but not adult (0.68 vs. 0.71) or old (0.71 vs. 0.78) rats. Muscle glucose transporter protein (GLUT4) content of the young rats was greater (p<0.05) than the adult or old rats. GLUT4 content of the young rats was unchanged 3.5 hr post-exercise. We conclude that 3.5 hr post-exercise muscle glucose transport rate is increased with a submaximally effective insulin concentration regardless of age, and 3-MG transport rate with a maximally effective insulin concentration is elevated in young rats despite unchanged GLUT4 content.

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21.18

INSULIN-SENSITIVE GLUCOSE TRANSPORTER (GLUT-4) LEVELS ARE ELEVATED IN HUMAN MUSCLE WITH ENDURANCE TRAINING. J.A. Houmard, M.H. Shinebarger, P.L. Dolan, C. McCulley, N.J. Bruno, R. Bruner*, R.G. Israel, and G.L. Dohm. East Carolina University, Greenville, NC 27858.

In a cross-sectional study, trained subjects possessed elevated GLUT-4 protein levels in comparison to sedentary controls (Houmard et al., Am. J. Physiol., 261:E437-E443, 1991). This study examined the hypothesis that muscle GLUT-4 levels are increased with training in humans with a longitudinal design. Thirteen middle-aged men (~47 y) were tested before and after a 14-wk training period (3-4 d/wk, 30-45 min/d). Muscle samples were obtained from the lateral gastrocnemius (needle biopsies) pre-training and 48-h after the final training bout; an insulin sensitivity index (ISI, Bergmans minimal model) was also determined at this time. ISI (p<0.03), GLUT-4 protein levels (Western Blot, p<0.001), and muscle citrate synthase activity (CS, p<0.001) significantly increased by ≈1.6 fold with training. The percentage of type IIa muscle fibers increased significantly (p<0.01) by ≈10% while the percentage of type IIb fibers decreased significantly (p<0.001) by a similar amount. Elevations in muscle GLUT-4 content and insulin sensitivity are therefore apparent with training, which may be partially associated with the conversion of type IIb to IIa muscle fibers.

21.19

COMPARISON OF GLUCOSE TRANSPORT WITH MUSCLE FIBER COMPOSITION, MUSCLE ACTIVITY, AND GLUT4.

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Rates of glucose transport differ in metabolically heterogeneous types of skeletal muscles. Therefore, we compared insulin-stimulated [^{3}H] 3-O-methyl glucose transport (3-O-MG) in perfused rat hindlimb muscles [soleus (SOL), plantaris (PL), extensor digitorum longus (EDL), tibialis anterior (TA), and the red (RG) and white gastocnemius (WG)] with their muscle fiber composition and their content of the insulin regulatable glucose transport protein (GLUT4). In addition, we quantified the normal muscle activities in the SOL and PL (Bonen et al.1990) every 2min for 24 h per day for 6 days. Among muscles the fiber composition ranged from 69-0% slow-twitch oxidative (SO), 68-31% fast-twitch oxidative glycolytic (FOG) and 84-0% fast-twitch glycolytic (FG). A good relationship was found between insulin-stimulated 3-O-methyl glucose (3-O-MG) transport (nmol/mg wt/5min) and GLUT4 (R^2=0.996) among all muscles, except the TA. GLUT4 content was also highly correlated with the proportion of oxidative fibers (SO+FOG) (r=0.99). Based on two muscles (SOL and PL) relative differences (%) in normal muscle activity did not appear to be directly related to relative differences in either the insulin-stimulated 3-O-MG transport rate or to the GLUT4 content.

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21.20

GLUCOSE TRANSPORTERS IN REGENERATING SKELETAL MUSCLE.

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The glucose transporter isoforms GLUT 1 and 4 are essential for glucose metabolism in skeletal muscle. The relative concentration of these isoforms differ between fiber types, and change with development, aging, and physical training. Following transplantation, skeletal muscle fibers degenerate and new fibers regenerate. Using this model of muscle development, our purpose was to test the hypothesis that GLUT 1 and 4 would return to control value with time following transplantation. Soleus and extensor digitorum longus (EDL) muscles were orthotopically grafted with the nerve reimplanted in Wistar rats (female, 2 mo). Glucose transporters were isolated. Western blots were run and polyclonal antibodies raised against the 15 amino acid carboxy-terminus end of both the GLUT 1 and GLUT 4 proteins were used to visualize the GLUT 1 and 4 bands. In soleus grafts, GLUT 4 was not measurable at 7 days, evident at 21 days, and not different than control value at 42 days post-grafting. In contrast, EDL grafts evidenced a slight elevation in GLUT 4 at 7 days, and values were not different from control at 21 and 42 days. GLUT 1 was non-reactive in soleus muscles and grafts, and demonstrated low reactivity in EDL muscles and grafts. Supported by NIH DE-07687 and the University of California President's Fellowship Program.

21.21

EFFECT OF ENDURANCE TRAINING ON PYRUVATE METABOLISM IN MICE AFTER SUPRAMAXIMAL EXERCISE.

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In order to investigate effect of endurance training on pyruvate metabolism in mice after supramaximal exercise, male ddY mice (N= 9) ran at a speed of 30 m.min^{-1} for 60 min for 6 weeks. In a ^{14}C injection experiment, the speed was increased from an initial rate of 40 m.min^{-1} by 10 m.min^{-1} every 30 sec to exhaustion. [1-^{14}C] pyruvate (1.53×10^4 Bq.g^{-1}) was injected intraperitoneally immediately before the exercise. The trained mice ran significantly longer than the control mice (160 $\pm$ 10 sec vs. 130 $\pm$ 9 sec, mean $\pm$ SE). No significant difference was found in the blood pyruvate concentration after 20 min of recovery from the exercise between the two groups. No significant difference was also found in the amount of $^{14}CO_2$ expired during 20 min of recovery relative to the injected dose of ^{14}C-pyruvate (25.3% $\pm$ 1.9% vs. 23.8% $\pm$ 2.5%). The muscle ^{14}C-glycogen concentration after 20 min of recovery in the trained mice was significantly higher than that in the control mice (97.0 $\pm$ 19.8 dpm.mg^{-1} vs. 58.7 $\pm$ 10.2 dpm.mg^{-1}). These results suggest that endurance training does not activate oxidation of pyruvate, but it activates glycogen resynthesis from pyruvate in mice after supramaximal exercise.

21.22

POSSIBLE RELATIONSHIP BETWEEN CARBONIC ANHYDRASE III AND CARBOHYDRATE METABOLISM IN TYPE I SKELETAL MUSCLES.

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Carbonic anhydrase III (CA III) is the predominant isoform in skeletal muscle and specially in type I fibers where it is the most abundant cytosolic protein. We have previously shown that inhibition of CA III can improve the resistance to fatigue of type I muscles. We tested the hypothesis that this influence on fatigue was 1) due to the inhibition of an intracellular CA isoform and 2) related to an effect on glycolysis and/or glycogenolysis. Rat soleus (SOL) muscles were incubated with or without ethoxyzolamide (ETHOX 0.1mM), a potent CA inhibitor, and were submitted to a standardized fatigue protocol after a 45 min period of equilibration. Glucose-6-P (G6P), fructose-6-P (F6P) and fructose-1,6-P (F16P) contents were determined on freeze-clamped SOL samples. When ETHOX was added at the start of the equilibration period, a condition which leads to differences in tension production between both groups after only 1 min of stimulation, the concentrations of G6P and F6P were 4 to 5 fold higher in the ETHOX muscles than in the control muscles for the entire duration of the fatigue protocol while no difference was noted for F16P. When ETHOX was added only at the start of the fatigue protocol significant differences in tension production between both goups of muscles were seen only after 15 min of stimulation. A significant difference in G6P content between both groups was only observed after 30 min in the protocol. Collectively, these data support the idea that the loss of CA III activity can lead to an imbalance between production and utilization of hexosemonophosphates in type I muscles.

21.23

APPLYING THE CONCEPT OF SYMMORPHOSIS TO ENERGY METABOLISM IN MUSCLES: HOW MUCH ENZYME IS ENOUGH, BUT NOT TOO MUCH?

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The concept of symmorphosis proposed by C.R. Taylor and E.R. Weibel predicts that functional capacities should match, but not exceed, maximal physiological demands. To determine if the concept applies to pathways of energy metabolism in muscles, I first consider the nature of enzyme-catalyzed metabolic reactions. I then consider the relationships between maximal catalytic capacities at various steps in energy metabolism and maximal pathway flux rates in vivo. This leads to the following observations: (a) enzymes catalyzing reactions close to equilibrium occur at maximal activities in greater excess over maximal pathway flux rates than enzymes catalyzing reactions far from equilibrium, (b) maximal activities of rate-limiting enzymes are higher than maximal pathway flux rates where the latter are relatively low, (c) close matches between capacities at rate-limiting steps and maximal pathway flux rates occur where the latter are extremely high. I conclude that: (a) enzyme activities higher than maximal in vivo flux rates are not necessarily in "excess" of what are required, (b) symmorphosis is more closely realized with ever increasing maximal flux rates, (c) such close matching between capacities and rates in high flux systems may imply upper limits to the design of functional capacities in pathways of energy metabolism in muscles.

29.1

SLACK-RELAXATION: PASSIVE TENSION RELEASE INCREASES BLOOD FLOW AND $\dot{V}o_2$ OF CONTRACTING MUSCLE *IN SITU*. B. T. Ameredes[1], W. F. Brechue, M. M. Bamman, and W. N. Stainsby. Depts. of Physiology and Pharmacology, Univ. of Florida, Gainesville, FL 32610.

The passive tension, or preload, at optimal muscle length (L_o) in the pennate-fibered canine gastrocnemius-plantaris muscle can be a significant fraction of the developed afterload of isotonic contractions. Therefore, we investigated the effects of the removal of the preload during the relaxation phase of electrically stimulated, repetitively contracting muscle (1 contraction/s, 200 ms duration, 50 imp/s, 4V), over a 30 min period. Isotonic contractions (0.25-0.3·P_o) were produced with a pneumatic lever allowing removal of the preload between contractions. This resulted in shortening contractions initiated at L_o, followed by relaxation at a short length, wherein the muscle had no passive tension, or was "slack", with the cycle being completed by resetting to L_o just prior to the next contraction. Blood flow ($\dot{Q}$) and oxygen uptake ($\dot{V}o_2$) were measured before and during contractions. $\dot{Q}$ and $\dot{V}o_2$ at 3-5 min of contractions were increased by 23% and 17%, respectively, when the preload was removed (2.1 ml/min·g and 255 µl/min·g, n = 5), as compared to values when the preload was maintained at L_o (1.6 ml/min·g and 212 µl/min·g, n = 5). These differences were maintained at 30 min of contractions, when $\dot{Q}$ and $\dot{V}o_2$ were still 27% and 19% higher in the slack-relaxation group. Fatigue, measured at 30 min as a decrease in power/initial power production, was less when the preload was removed (-29% vs. -50%). These data demonstrate that the passive tension that is maintained when this muscle is held at L_o, *in situ*, can limit $\dot{Q}$ and $\dot{V}o_2$, and can increase fatigue of repetitive isotonic tetanic contractions. We conclude that the slack-relaxation method results in less $\dot{Q}$ limitation and produces a contraction-relaxation cycle that better approximates cyclical muscle function *in vivo*. (Supported by NIH Grant AR39378 and [1]AHA Fellowship 91F/8.)

29.2

DISSOCIATION OF METABOLIC AND MECHANICAL RECOVERY AFTER REPETITIVE CONTRACTIONS OF MUSCLE *IN SITU*. W.F. Brechue, B.T. Ameredes[1], and W.N. Stainsby, Departments of Physiology and Pharmacology, College of Medicine, University of Florida, Gainesville, FL 32610.

To evaluate the mechanical and metabolic correlates of recovery, the dog gastrocnemius-plantaris muscle group was stimulated to perform 1/second isotonic, tetanic contractions. Each contraction was produced by a 200 msec train of impulses at 50/sec. The contractions were initiated from L_o with the load 0.5 x P_o. Oxygen uptake, $\dot{V}o_2$, and mechanical performance were measured during 30 minutes of contractions and during 300 minutes of recovery. During the contractions, $\dot{V}o_2$ and performance decreased approximately 40%. After 10 min of recovery, $\dot{V}o_2$ decreased to about twice the precontraction rest level. Thereafter, $\dot{V}o_2$ declined slowly reaching the rest level in 40 min. Muscle performance, monitored by single contractions at intervals, recovered slowly, reaching 80-90% of the initial level by 300 minutes. This pattern of slow recovery is similar to that observed previously after twitch contractions (B.A. Wilson and W.N. Stainsby, J. Appl. Physiol. 45:234-237, 1978). The level of mechanical recovery achieved suggests that irreversible damage was minimal. The dissociation of metabolism and mechanical performance during recovery suggests mechanical recovery is not related to the energetic state of the muscle under the conditions of these experiments. Therefore, the decrease in muscle performance during the contractions must be a result of other factors. (Supported by NIH Grant AR39378 and [1]AHA Fellowship 91F/8).

29.3

AGING, ENDURANCE TRAINING, AND MUSCLE METABOLISM DURING EXERCISE. A.R. Coggan, A.M. Abduljalil*, S.C. Swanson, J.W. Farris, M.S. Earle, L.A. Mendenhall*, and P.-M. Robitaille*. Ohio State University, Columbus, OH 43210.

To examine the effects of aging and/or endurance training on muscle metabolism during exercise, ^{31}P magnetic resonance spectroscopy (^{31}P-MRS) was used to study the metabolic response to exercise in young (Y) and older (O) untrained (UT) and endurance-trained (T) men. Exercise consisted of plantar *flexion* at 0.5 Hz, with the power output incremented by 0.74 W every 3 min until fatigue. ^{31}P-MRS data were acquired at rest and during the last ~90 s of each exercise stage using a 1.5 tesla MR spectrometer and a 4 cm surface coil placed over the lateral gastrocnemius muscle. The rate of increase in the P_i/PCr ratio with increasing power output (i.e., the P_i/PCr slope) was used as a measure of muscle metabolic stress. Results are summarized in the table below:

		Physical characteristics		Plantar flexion exercise	
Group	n	Age (y)	VO_2max (mL/min/kg)	Peak power (W)	P_i/PCr slope (1/W)
YUT	6	25±1	47.6±2.0	4.6±0.4	0.043±0.010
OUT	4	62±1	30.5±3.1*	3.5±0.4*	0.076±0.013*
YT	4	29±2	67.4±2.2$	6.1±0.6$	0.018±0.002$
OT	6	62±1	52.0±1.1*$	4.6±0.4*$	0.038±0.005*$

Values are $\bar{x}$±S.E. *Significantly different from corresponding Y group. $Significantly different from corresponding UT group.

Age-related reductions in exercise capacity appear to be due in part to an altered muscle metabolic response to exercise. Differences were observed in T as well as in UT subjects, suggesting that these effects are not solely due to inactivity.

29.4

EFFECT OF PROLONGED TETRODOTOXIN-INDUCED NEURAL INACTIVATION ON ENZYMES OF ENERGY METABOLISM IN INDIVIDUAL RAT MUSCLE FIBERS. R.N. Michel, M. Chi*, H. Falter*, and O.H. Lowry*. Laurentian University, Sudbury, Ontario, P3E 2C6 and Washington University School of Medicine, St. Louis, Missouri 63110.

We have measured the changes in enzymes of energy metabolism of muscle fibers following a complete and prolonged muscle paralysis achieved without denervation. The propagation of sciatic nerve action potentials in one hindlimb of Sprague-Dawley rats were blocked with the sodium channel blocker tetrodotoxin (TTX) using a mini-osmotic pump and cuff delivery system. Two wks of TTX-induced paralysis caused severe wasting of plantaris (41%) and soleus (47%) muscles compared to sham-operated contralateral counterparts. The activities of hexokinase (HK), glycogen phosphorylase (PHRL), glycerol-3-phosphate dehydrogenase (GPDH), pyruvate kinase (PK), lactate dehydrogenase (LDH), malate dehydrogenase (MDH), citrate synthase (CS), ß-hydroxy-acyl-CoA dehydrogenase (ßOAC), and thiolase (TH), were measured in fiber bundles and individual fibers from these muscles. Consistent with the loss in mass, absolute amounts of all enzymes, except HK, were on average 65% lower in fiber bundles from TTX-treated plantaris. After TTX-induced disuse, HK activity (mol h^{-1} kg^{-1} dry wt) in plantaris and soleus was higher, and PHRL activity lower, in bundles and individual fibers of these muscles. Furthermore, in disused plantaris, PK activity was lower, and LDH activity not changed. It seems clear from individual fiber samples that only plantaris Type I and IIA fibers (~50% of the muscle) have reduced activities of enzymes of oxidative metabolism resulting from TTX inactivity. In TTX-treated soleus fiber bundles, a less marked, but substantial, loss in the amount of oxidative enzymes (on average 44%) was observed , accompanied by either an increase, or no change, in activities of 3 of 4 glycolytic enzymes (GPDH, PK and LDH). It appears that soleus, but not plantaris, fibers can compensate for the loss of oxidative metabolism that results from total disuse.

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29.5

ENZYMES OF ENERGY METABOLISM IN OVERLOADED RAT PLANTARIS MUSCLE FIBERS. H. Falter*, R.N. Michel, M. Chi*, and O.H. Lowry*. Laurentian University, Sudbury, Ontario, P3E 2C6 and Washington University School of Medicine, St. Louis, Missouri 63110.

Compensatory hypertrophy of the rat plantaris muscle was induced via the bilateral surgical removal of the synergistic gastrocnemius and soleus muscles. After 4 wks of work overload, plantaris muscle mass was 44% greater than sham-operated controls. The activity of the following nine enzymes of energy metabolism was measured from dissected fiber bundles derived from these muscles: hexokinase (HK), glycogen phosphorylase (PHRL), glycerol-3-phosphate dehydrogenase (GPDH), pyruvate kinase (PK), lactate dehydrogenase (LDH), malate dehydrogenase (MDH), citrate synthase (CS), ß-hydroxy-acyl-CoA dehydrogenase (ßOAC), and thiolase (TH). After four wks of muscle overload HK activity (mol hr^{-1} kg^{-1} dry wt) was similar to control muscle. Similarly, in overloaded plantaris, the concentrations of two enzymes characteristic of fatty acid metabolism, ßOAC and TH, were not different from sham-operated muscles. Moderately reduced as a result of functional overload were the activities of enzymes of oxidative metabolism, MDH (20%) and CS (16%). Severely compromised were the activities of the glycolytic marker enzymes GPDH (51%), PK (45%), and LDH (24%) in hypertrophied plantaris. Interestingly, PHRL, an enzyme responsible for glycogenolysis, was also 49% lower after overload. It seems clear from our results that in the overloaded plantaris, levels of a majority of the measured enzymes do not increase in proportion to the large increase in muscle mass (i.e. enzyme dilution; HK and ßOAC being the exceptions). The results are consistent with an attempt by the muscle to shift towards greater oxidative capacity at the expense of glycolytic capacity.

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29.6

EFFECTS OF SHORT-TERM OSCILLATORY TRAINING FOLLOWING A CONTINUOUS TRAINING REGIME ON SKELETAL MUSCLE ENZYME ACTIVITIES AND EXERCISE PERFORMANCE. P. Willis and W.S. Parkhouse. Kinesiology, Simon Fraser University, Burnaby, B.C., Canada V5A 1S6

The purpose of this study was to examine the effects of a high intensity short duration (3 weeks) oscillatory training regime following a continuous training regime (12 weeks) on exercise performance in female Sprague Dawley rats. The continuous trained (CT) rats were subjected to a progressive treadmill training regime for a total of 15 weeks with the final workload being: 32.5 m/min; 60 min. duration; 8% incline; 5 times per week. The oscillatory trained (OT) animals did the same training regime for the first 12 weeks. During the last three weeks they alternated 5 min. of high and 5 min. of low intensity running. Mean velocity and total distance covered were identical to the CT group. Twenty-four hours after the last training session, the animals were exercised (40 m/min; 8% incline) until they could no longer run at this velocity. Control familiarized animals lasted less than 5 minutes whereas the CT and OT groups ran for 72±5 and 115±7 minutes respectively. Enzymatic profiles were obtained from the white and red gastrocnemius, plantaris and soleus muscles. In general, citrate synthase, malate dehydrogenase and creatine kinase activities were increased with training and no consistent differences existed between the CT and OT muscles. Furthermore, no differences were observed in initial substrate levels and both groups demonstrated similar ultrastructural disruption, and metabolite levels at the end of exercise. It appears that other factors are responsible for the increased endurance capacity of OT animals.

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29.7

EFFECTS OF EXERCISE TRAINING AND AGE ON IMP PRODUCTION AND ENERGY CHARGE IN FISCHER 344 RAT GASTROCNEMIUS MUSCLE.

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A reduction in work capacity (WC) is observed with aging and exercise training (ET) attenuates this decline, which may be reflected in the muscle's energy charge (EC = ATP/ADP). ET enhances the respiratory enzymes that defend EC. So, the interaction of age and ET (12 wks, 5 days/wk) on muscle EC during simulated exercise was studied in anesthetized (ketamine 80 mg/kg b.w. and acepromazine 0.5 mg/animal) old (O = 25 mo, n = 10), mature (M = 17-19 mo, n = 10), and adult (A = 12-13 mo, n = 13) F-344 female rats. An achilles tendon and sciatic nerve were isolated for tension measurement and electrical stimulation. The gastrocnemius was freeze clamped, with tongs precooled in liquid N_2, during electrical stimulation (4 min, 8 V, 8 Hz). Nucleotides and IMP were analyzed in freeze dried samples by reverse-phase HPLC (Beckman). A graded treadmill pretest showed equal WC between ages (O, 45.2; M, 53.4; A, 52.0 $kg*m^2/s^2$). The post-test showed an equally increased WC (O, 108.6; M, 97.7; A, 126.6 $kg*m^2/s^2$) in all age ET groups. The A and M sedentary (S) groups maintained WC; the old S group declined to 23.2 $kg*m^2/s^2$. The EC was equal at rest across age groups (O 7.4, M 7.2, A 7.6 ATP/ADP). During simulated exercise the EC was equally reduced across age and training (S-O, 3.4; ET-O, 4.2; S-M, 3.8; ET-M, 3.0; S-A, 3.5; ET-A, 3.6 ATP/ADP). The IMP accumulation was greater in S-A than in ET-A (35.8 vs 23.5% total nucleotides). We conclude that aged animals maintain their response to ET, and the enhanced WC is not reflected in an increased EC during simulated exercise. However, ET may influence the purine nucleotide cycle. (supported by AFAR, AHA of Colorado and NIA animal colony)

29.8

CAT "FAST" MUSCLES MAY LACK IIB MYOSIN HEAVY CHAINS.

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Using Ca^{++} activated mATPase and succinate dehydrogenase activity, cat *biceps brachii* (BB) have been characterized as ≈75% fast glycolytic, ≈20% fast oxidative glycoytic (FOG) and ≈5% slow (SO), cat soleus (SOL) muscles were ≈92% SO and ≈8% FOG (Meyer et al., Am.J. Physiol.248:C279,1985). Jiang et al. have reported that the cat medial gastrocnemius (MG) muscle demonstrates 62% "fast"mATPase activity (Am.J. Physiol. 259:C507,1990). In the present study samples from these cat muscle types were examined to determine the distribution of myosin heavy (MHC) and light (MLC) chains present. Muscle samples (n=3) weighing (g), 0.31±0.01 (BB), 0.35±0.06 (MG), and 0.17±0.06 (SOL), were extracted and myofibril fractions produced via serial homogenization in sucrose, Triton-X and KCl solutions. MHC and MLC were identified by denaturing SDS-PAGE. Rat muscles of known myosin composition were run as standards on each gel. Relative MHC and MLC content was determined via scanning densitometry. Cat BB and MG had MHC bands corresponding to IIA and I MHC and SOL one band corresponding to type I MHC in the rat. The light chain pattern in the cat BB and MG indicated the presence of fast light chain (FLC) 1 and FLC 2. Assuming the MHC and MLC banding pattern for cat and rat are the same, these muscles appear either to lack or express undetectable levels of type IIB MHC and FLC3 .

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29.9

ATP TURNOVER DURING EXERCISE IN HUMAN SKELETAL MUSCLES WITH DIFFERENT FIBRE TYPE COMPOSITION.

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During intense exercise there is a large increase in ATP turnover which is probably greater in fast twitch (FT) fibres rather than in slow twitch (ST) fibres. In a mixed muscle therefore, ATP turnover during maximal exercise should be proportional to the percentage of FT fibres. We have measured metabolites in the adductor pollicis (AP) and abductor digitii minimi (ADM) muscles using ^{31}P magnetic resonance spectroscopy with ethical approval. ATP turnover was calculated from changes in phosphocreatine (-ΔPC), lactate production (1.5xΔLA) and -ΔATP resulting from fifty 100 ms isometric contractions induced by electrostimulation (50Hz). Values are means±SEM and concentrations are estimates in intracellular water.

	n	ΔPC (mM)	ΔATP (mM)	ΔLA (mM)	ATP turnover (mM s^{-1})
AP	8	-17.0±1.6	-1.0±0.8	14.1±2.2	8.0±0.9
ADM	8	-23.5±1.2*	-1.2±0.7	28.8±2.0*	13.6±0.7*

The ADM had significantly greater PC breakdown, lactate production and thus a greater ATP turnover than the AP during ischaemic exercise (*; $p<0.05$; T-test). The ADM is reported to consist of 48% FT fibres whereas the AP has 20% FT fibres (Johnson et al, *J.Neurol.Sci.* **18**,111-129). From the data, calculated ATP turnover is 6 fold greater in FT fibres compared to ST fibres during maximal exercise (24 vs 4 mM ATP s^{-1}, respectively).

29.10

ENDURANCE EXERCISE EFFECTS ON SINGLE SKELETAL MUSCLE FIBRE CONTRACTILE PROPERTIES OF DYSTROPHIC MDX MICE.

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The possible amelioration of the debilitating effects of muscle diseases, such as Duchenne Muscular Dystrophy (DMD) led to an investigation into the effects of exercise on dystrophic mice. Mdx mice (an animal model of DMD), underwent a 15-week endurance exercise program, consisting of 2 hours/day, 5 days/week of tail-weighted swimming. At the conclusion of the training period, single fibres were prepared from the EDL and soleus (SOL) muscles of both SWIM and SEDENTary mdx mice, attached to a sensitive isometric force transducer, and activated in Ca^{2+}- and Sr^{2+}-buffered solutions. On the basis of their contractile properties, fibres were separated into discrete fibre types. In the EDL, type IIB fibres from the SWIM group were significantly less sensitive to Ca^{2+} and Sr^{2+} compared to those from the SEDENT group, with no major differences in contractile characteristics evident in type IIA fibres. In the SOL, type I contractile characteristics did not differ between groups. However, the fast-twitch IIA fibres, were significantly less sensitive to both Ca^{2+} and Sr^{2+}. Histochemical staining of whole muscle cross-sections revealed exercise-induced fibre type shifts towards a greater oxidative capacity in the both muscles. The exercised group also exhibited an increased incidence of SOL fibres with characteristics intermediate to those of the fast- and slow-twitch fibre types, suggesting possible exercise-induced fibre-type transformations as an adaptation to the functional demand.

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29.11

Theophylline Improves Exercise Capacity. G. D. Marsh, R. McFadden, R. T. Thompson and D. H. Paterson. Department of Nuclear Medicine and Division of Respirology, St. Joseph's Health Centre, and The Lawson Research Institute, The University of Western Ontario, London, Ontario, Canada. N6A 4L6

The purpose of this study was to examine the effect of the methylxanthine compound theophylline, on muscle metabolism during incremental exercise, using ^{31}P nuclear magnetic resonance spectroscopy (NMRS). Six healthy males (37±14 yrs) volunteered to participate in the study. Each subject performed repeated forearm ramp exercise tests to fatigue, with at least 72 hours separating the two trials. A control group (n=3) were not given the drug. The experimental group (n=3) repeated the protocol after receiving 300 mg of sustained release theophylline every 12 hours. ^{31}P spectra were acquired every 36s throughout exercise and the relative concentrations of the phosphate metabolites and intracellular pH were calculated from these spectra. Power output at the onset, or threshold of intracellular metabolic acidosis (IT) was identified using piecewise linear regression, from changes in Pi/PCr and pH. Both maximal power (1.87±0.28 W and 1.91±0.53 W), and the power output at the IT (1.18±0.15 W and 1.22±0.11 W) were reproducible in the control group. Following theophylline administration, the maximal power attained by the experimental group increased significantly ($p<0.05$) by 19% (from 2.25±0.2 W to 2.68±0.22 W). A similar trend occurred in the onset of the threshold which was also prolonged by 19% (from 1.33±0.18 W to 1.58±0.22 W). Therapeutic *concentrations* of theophylline delayed the onset of intracellular metabolic acidosis, significantly increasing the endurance of the forearm musculature. These findings suggest an enhancement of oxidative metabolism. The drug may have improved the oxidative capacity of muscle by increasing the availability of fat as a substrate, or enhancing perfusion of the working tissues.

29.12

ROLE OF NEUROMUSCULAR ACTIVITY IN CONTROL OF METABOLIC GENE EXPRESSION IN SKELETAL MUSCLE.

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Neuromuscular activity plays an important role in the induction and modulation of the contractile and metabolic properties of skeletal muscle. We have investigated the effect of complete block of neuromuscular transmission on the expression of 2 metabolic transcripts in predominantly fast-twitch tibialis anterior (TA) in rat. Botulinum toxin (BTX) A was injected into the exposed TA (4ng in 2ul) in one leg. The contralateral TA served as a control. The recovery of muscle contractile function was determined in situ at 7, 14, 21 and 120 days following a single injection of BTX. Total RNA was extracted from injected and control muscles at the same experimental intervals and analyzed using cDNA probes for the metabolic enzymes, glycogen phosphorylase (M-GP) and lipoprotein lipase (LPL). Muscles were completely blocked 7 days after treatment, showed approximately 10% contractile recovery at 14 days, and complete recovery by 120 days. Expression of M-GP RNA was reduced by 37% at 7 days and 71% at 14 days, but had recovered to 86% of control at 120 days. LPL expression doubled at 7 days and 14 days, and remained 16% higher than control at 120 days. The increased expression of LPL may also be responsible for the increase in muscle resistance to low frequency fatigue. The data indicate that aspects of neuromuscular activity effect metabolic gene expression in skeletal muscle. (Supported by VA Grant 151C1 and the California Affiliate of the AHA)

29.13

EFFECT OF ENDURANCE TRAINING ON CHANGES OF THE RAT SOLEUS MUSCLE DURING HINDLIMB SUSPENSION. Hideyuki Takahashi[1], Yuji Itai[1]* and Shigeru Katsuta[2]. [1]Dept. of Radiology, Inst. of Clinical Medicine and [2] Health & Sport Sciences, Univ. of Tsukuba, Tsukuba 305, Japan.

We exemined the effect of prior 10-wk endurance training on changes in the histochemical and biochemical properties of the rat soleus muscle during hindlimb suspension(HS) for up to 4 wks. Male Wistar strain rats were divided into training+ suspension(Tr+SUS), suspension only(SUS) and control (CON) groups. The muscle-to-body weight ratio decreased markedly during HS, and at similar rates in both Tr+SUS and SUS groups. However, as this ratio in the Tr+SUS group had been increased by the training, it remained higher than in the SUS group. Similar pattern was observed with respect to succinate dehydrogenase(SDH) activity. Myosin heavy chain(HC) IId, most likely corresponding to HCIIX, was detected in the suspended soleus, and its percentage increased during the experimental period. The percentage of HCIId and number of rats with HCIId was lower in the *Tr+SUS* group than in the SUS group. These results suggest that endurance training before HS contributes to maintenance of higher muscle mass and SDH activity during HS and inhibits the expression of HCIId in the suspended soleus.

29.14

Role of albumin in the work-induced hypertrophy of rat skeletal muscle

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The work-induced hypetrophy in the rat skeletal muscle accompanies the increase in quantity of albumin in the muscle. Physiological role of albumin in the muscle enlargement have been studied by use of the mutant rat defective in albumin synthesis.The work-induced hypertrophy in the skeletal muscle which is generally observed in normal rats, fails to take palace in albumin deficient rat (NAR).Inability of NAR to develop the work-induced muscle hypertrophy is not the consequence of the lowered inborn level of testosterone and growth hormone but primarily due to the absence of albumin in NAR. New muscle fiber is formed by work-induced hypertrophy of the skeletal muscle in the normal rat.Albumin localized in the epimysium of the the control muscle. Albumin localized in the epimysium and small muscle fiber in the hypertrophied muscle. Myosin heavy chain in these small fiber was embryonic type. Albumin appeared in the immature muscle fiber and disappeared in the adult muscle fiber.Therefore, albumin may related to proliferation of muscle fiber in the hypertrophied skeletal muscle in the normal rat.

29.15

PROGRESSIVE OVERLOAD OF THE ANTERIOR LATISSIMUS DORSI OF THE ADULT QUAIL PRODUCES MUSCLE FIBER HYPERTROPHY PRIOR TO FIBER HYPERPLASIA

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Muscle fiber hyperplasia precedes fiber hypertrophy in the anterior latissimus dorsi (ALD) muscle of adult quail undergoing chronic stretch (Alway et al., 1990) This study was undertaken to determine if a stretch protocol involving a progressive increase in load and duration would induce significant muscle fiber hypertrophy followed by fiber hyperplasia. Sixteen adult quail were used in this study. The stretch protocol was as follows: Day 1 (a weight equal to 10% of birds mass was wrapped around the right wing, while the left side served as the intra-animal control), Day 2,3 (Rest), Day 4 (15%), Day 5,6,7 (Rest), Day 8 (20%), Day 9,10 (Rest), Day 11,12,13,14 (25%), Day 15,16 (Rest), Day 17-38 (35%). There were no rest intervals during the 35% weighting period. Birds were sacrificed after 16, 20, 24, or 28 days of stretch. The ALD was removed and its mass and length determined. The muscle was divided into proximal, middle, and distal segments and processed for histochemistry. Muscle mass increased 195.7%(16d), 239.6%(20d), 254.2%(24d), and 331.0%(28d) relative to the control. Muscle length increased 33.0%(16d), 61.3%(20d), 46.3%(24d), and 53.9%(28d). Slow tonic fiber area increased 110.8%(16d), 65.6%(20d), 92.9%(24d), and 50.9%(28d). Additionally, fiber number changes were -2.4%(16d), 13.7%(20d), 20.2%(24d), and 60.8%(28d). The changes in the % non-contractile tissue were 2.3%(16d), 10.0%(20d), 8.3%(24d), and 4.9%(28d). These data indicate that in avian muscle undergoing progressive overload, increases in muscle length, muscle fiber area, fiber number, and non-contractile tissue contribute to the muscle mass increase; however, fiber hypertrophy contributes primarily to the initial muscle mass increase while fiber hyperplasia occurs only after prodigious increases in muscle mass (~331%). Additionally, increases in muscle fiber area are maximal after 16d of progressive overload. These data suggest that muscle fiber hyperplasia occurs after a critical fiber size is attained. (NIH #AR40056)

29.16

SELECTIVE MUSCLE HYPERTROPHY AS A RESULT OF STRENGTH TRAINING. Marco V. Narici and Paolo Cerretelli. CNR, Istituto Tecnologie Biomediche Avanzate, Reparto Fisiologia, Milan, Italy 20131

The effects of six months strength training on the morphometry of the human quadriceps muscles was investigated in a group of seven male subjects (age 29.0±3.6 yr, weight 79.3±9.8 kg, height 1.83±0.06 m, means±SD). Training consisted of 4 series of 6 unilateral leg lifts of a weight corresponding to 80% of the one repetition maximum (1RM) carried out every other day, for 6 months. Before and after training the cross-sectional areas (CSA) of the quadriceps as a group and of its constituent muscles were measured by nuclear magnetic resonance imaging at five levels along the femur, interspaced by a distance of 1/10 femur length (Lf). It was obseved that the degree of hypertrophy for the quadriceps group was not uniform: it was maximum both at the proximal 3/10 Lf (18.8%±3.6 %) and distal 7/10 Lf (19.3%±3.4%) but minimum at 6/10 Lf (13.0%±3.6%), near mid-femur (means±SD). These different percentage changes in the CSA along the quadriceps reflected the pattern of hypertrophy of its constituent muscles. The rectus femoris, for instance, increased in CSA by 54.6%±19.1% at 7/10 Lf but only by 8.6%±3.4% at 3/10 Lf. On the contrary, the vastus medialis and vastus intermedius showed the highest increase in CSA at 3/10 Lf: 28.7%±15.2% and 23.1%±4.6%, respectively. The vastus lateralis showed a maximum increase of 21.6%±6.3% at 7/10 Lf but a minimum of 7.0%±0.8% at 5/10 Lf. Also, in all four muscles, the pattern of hypertrophy along their belly was by no means uniform, the rectus femoris showing the largest differences. These results suggest that 1) the ripartition of the external load between the muscles belonging to the same muscle group may not be uniform and 2) some portions along the muscle belly are subjected to higher forces than others.

29.17

L- CARNITINE AND AEROBIC EXERCISE OVER SKELETAL MUSCLE FIBRE SIZE AND FIBRE TYPE DISTRIBUTION IN RATS.

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The effect of chronic administration for 12 weeks of an ergogenic drug, l- Carnitine (Secabiol) was studied in two skeletal muscles: soleus and gastrocnemius.

The drug were administered daily by intragastric probang, to rats at rest and while performing running exercise during 12 weeks. Animals were male Wistar postpuberale rats; four groups were stablished, each one consisting in six animal: control and l- carnitine- treated groups, with and without exercise.

Rats were killed by anaesthetic overdose and skeletal muscles excised and weigthed. Cryostac sections (10µm) were stained histochemically for myosin ATPase readtion after preincubation at pH 9.8, 4.4 , and 4.2 to determine fibre type distribution. Stereologic analysis were then performed by IBAS 2.

Changes in fibre type distribution were modest, with a sligh trend to increase I and II A fibres average with exercise, and no changes due to l-carnitine administration. Specific hypertrophy of type I fibres could be conclusively demostrated in red portion of lateral gastrocnemius, areas values 3.145±42 vs 2.732±35. The fibre size decrease in exercise groups.

29.18

Is the fraction of type I fibers in different muscles related?

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The two main muscle fiber types (type I and type II) in man have different properties, and the fraction of each type varies between muscles and subjects. Normal exercise involves a number of muscles, but most studies classify the fibers in only one muscle, e.g. the *m. vastus lateralis*. It is not known whether the information obtained is relevant for other working muscles. Therefore, data previously published by Johnson *et al.* (*Neur. Sci.* **18**:111-129, 1973) were reexamined. These authors determined the fraction of type I fibers in 50 different muscle sites on six subjects. Their data have been analysed by a standard two-way analysis of variance, assuming that the fraction of type I fibers in each sample was the sum of a muscle term, a subject term, and a random variation (residual). The statistical analysis revealed *significant differences* between subjects and muscles. The random variation was 0.08 (8 percent points), and the residuals appeared normally distributed as the model requires. The model suggests the following: Assume that for two subjects the fraction of type I fibers differs by Δ in one muscle, and disregard the random variation. Then the fraction of type I fibers for the two subjects differs by Δ in all muscles. Example (with random variation included): The data on 17 leg muscle on subjects #2 and #4 (S2 & S4) in Johnson *et al's* study, were compared. In average the fraction of type I fibers in S4 was 0.08 larger than for S2. Single analysis showed that the fraction of type I fibers for S4 was larger than for S2 in 15 out of 17 muscle. *Conclusion*: The fraction of type I fibers in one muscle provides relevant information for other muscles when different subjects are compared.

29.19

Muscle composition of various elite athletes by MRI

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Since manners and activities of physical activities vary greatly depending on the type of the events, continuous training specific to a certain event may effect morphological characteristics of femoral muscles. No study has been made on muscle morphology of whole femoral part, although muscle belly has mainly been evaluated. In this study, the characteristics of muscle composition in the whole femoral part were evaluated in excellent male and female athletes in various events using MRI. Sixty-six of male and female athletes within the ranks of top 10 in Japan or member of all Japan in 8 events were employed. Twenty male and female in the control group were also subjected. In determination of muscle cross-sectional area by MRI, longitudinal section was first imaged, and the image thus obtained was used to identify greater trochanter and outed intercondylar tubercle of shank. From the position of 70% of the distance from intercondylar tubercle, 12 axial images in MRI were subsequently taken at a same interval of distance toward the knee. From axial images obtained, the cross-sectional areas of quadriceps muscle (extensor) and biceps muscle (flexor) were calculated. With regard to the characteristics by the event in male athletes, the subjects were classified into two types. In one type, both muscle groups (extensor and flexor) in upper femoral part were greatly developed but not in lower part (Ex. T & F). In the other type, both of the upper and lower femoral parts showed great development (Ex. Soccer). Female athletes did not exhibit difference by sites so significantly as in male players. The male athletes did not always showed the difference in muscle cross-sectional area compared that in the control group, while female athletes indicated significantly high values at any position of slices.

29.20

FIBRE TYPE SPECIFIC CHANGES IN RAT MUSCLE METABOLITES DURING FATIGUING EXERCISE.

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As a result of high-intensity exercise large changes occur in muscle metabolite concentrations (e.g. phosphocreatine (PC), Pi, lactate, ATP, IMP) which may be associated with fatigue. During repetitive contractions the magnitude of fatigue was found to vary with changes in ATP and IMP, while no differences are seen in PC and lactate changes (e.g. de Haan, Exp. Physiol.75,851-854,1990). In contrast to the large increase in IMP, the ATP remaining for the whole muscle would still be too high to affect contractile activity. However, ATP and IMP changes might vary markedly amongst different fibre populations. In the present study individual fibres dissected from the medial gastrocnemius muscles of anaesthetized rats (pentobarbitone 60mg/kg, i.p.) were classified as type I, IIA, IIBd and IIBm, according to Lind & Kernell (J.Histochem.Cytochem. 39,589-597,1991). Metabolite changes were determined in the different fibre populations, respectively. The rat muscles were stimulated in situ, performing 15 successive maximal dynamic contractions within 6s, with occluded blood flow. At the end of the exercise work output had decreased to 49% of that in the first contraction. While IMP production was 14 µmol/gdw for the whole muscle, in type I fibres hardly any IMP was produced. Conversely, the type IIBm population, which has the highest glycolytic activity, showed some fibres with IMP values higher than 20 µmol/gdw. The results indicate that as a result of fatiguing exercise, the ATP concentration can become below 1mM in some fibres within mixed muscles which may play a role in the regulation of contractile function of those fibres and hence of the whole muscle.

29.21

EFFECT OF SHORTENING VELOCITY ON GLYCOGEN DEPLETION IN DIFFERENT HUMAN MUSCLE FIBRE TYPES.

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Surprisingly few data are available on the effect of shortening velocity on glycogen depletion in human exercise (see Gollnick et al., 1974, J. Physiol. 241, 45-57). In this investigation 4 subjects performed 12 min of exercise on a cycle ergometer at 90% VO_{2max} pedalling at 60 and at 120 rev/min. VO_{2max} and hence the VO_2 of the experimental exercise was the same at both rates. Vastus lateralis was biopsied before and after exercise. Serial sections of the biopsies were PAS stained for glycogen content and histochemically fibre typed (Lind & Kernell, 1991, J. Histochem. Cytochem. 39, 589-597). Following exercise at 60 rev/min the optical density of the PAS stain was significantly reduced by 28, 23, and 11% respectively in type I, IIa and IIb fibres ($p<0.05$): after exercise at 120 rev/min the reduction was greater in all fibre types (viz 46, 37 and 31% respectively: $p<0.05$). The data suggests that type I fibres remain recruited at 120 rev/min, although since they may be operating on the descending right arm of their power/velocity and efficiency/velocity relationships, they may contribute proportionately little power for a high energy turnover resulting in rapid depletion of glycogen.

29.22

FIBRE TYPE PROPORTIONS AND SIZES, AND OXIDATIVE CAPACITY IN DIAPHRAGM OF HIBERNATING SQUIRRELS.

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The purpose of this study was to examine the effects of hibernation on diaphragm (DIA) muscle mass, fibre type proportions and sizes, and oxidative capacity in the squirrel. DIA muscle biopsies from the costal region were obtained from 7 fall-awake (FA), 10 winter-awake (WA), and 8 hibernating (H) ground squirrels (Spermophilus lateralis). Biopsies were quick-frozen, stored at -70°C., and later, sectioned and processed for NADH-TR reaction end-product and myofibrillar-ATPase (M-ATPase). Using an image analysis system, muscle cross-sectional areas and optical densities were determined from cross-sections of DIA processed for NADH-TR end-product reaction. From serial sections stained for M-ATPase, the same fibres were typed as type 1, 2a, 2b, or 2c. H and WA squirrels had lower body weights but similar DIA mass than FA squirrels. Hibernators had more type 2b fibres and fewer type 2a fibres in the DIA than WA squirrels. Hibernators had larger type 1 and 2a fibres in the DIA than FA and W squirrels and larger type 2b fibres in the DIA than FA squirrels. The type 2b fibres of WA squirrels were more oxidative than than those in FA squirrels. Hibernators may have larger fibres and more type 2b fibres in the DIA to work against a stiffer chest wall and lungs.

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29.23

IMPROVED MUSCULAR PERFORMANCE OF THE MDX MOUSE FOLLOWING ENDURANCE EXERCISE AND CLENBUTEROL ADMINISTRATION.

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An X-linked recessive inheritance and a lack of dystrophin makes the mdx mouse a good model for Duchenne Muscular Dystrophy (DMD). Mdx mice (6 weeks of age) underwent a 15 week endurance swimming program. Following training, both the intact extensor digitorum longus (EDL) and soleus muscles exhibited a significantly improved resistance to fatigue. Since this reduced fatiguability is beneficial to dystrophic muscle, the possibility exists that non-weight bearing exercise could have therapeutic effects on DMD patients. In order to complete such a training program, DMD patients would need to have a greatly improved muscle bulk at the beginning of the exercise. For this reason, the beta-agonist clenbuterol (a potent stimulator of muscle growth) was fed to mdx mice as they underwent a similar endurance exercise program. Clenbuterol treated mice had 10-20% larger increases in body weight than untreated mice. The contraction and relaxation times of the EDL and soleus were faster in the clenbuterol-treated animals, supported by type I to type II fibre type transitions in the soleus. Clenbuterol increases muscle bulk by reducing protein degradation and alters the calcium handling properties of mdx muscles. Both of these factors have important implications in the possible treatment of human DMD patients.

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29.24

EFFECT OF ENDURANCE RUNNING TRAINING ON PARTIALLY DENERVATED RAT SOLEUS MUSCLE.

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Many reports investigating the structural, mechanical, and biochemical properties of completely denervated muscles of experimental animals have been presented. However, we often encounter clinical cases of skeletal muscle tissues that have suffered from incomplete or partial denervation through various injuries. Partial denervation can be carried out by cutting the distal root of the nerves innervating the soleus muscle. Partial denervation, by 30 % or less, of the nerve supply did not cause apparent diminution of the number of muscle fibers, nor any appreciable alteration in the nature of the remaining nerves. The decrease of fast-twitch fibers, with grouping atrophy, was extensive by 6 weeks after denervation, involving not only the denervated area, but also the rest of the muscle. After 8 weeks, the number of atrophied fibers clearly decreased and fibers with the central nucleus covered a wide muscle area. These structural changes tended to occur during the earlier stages of the exercise periods, as compared with the denervation-only group. The levels of oxidative and glycolytic enzyme activities show the same trend as in the group of continuous treadmill running for 90 min at a speed of 30 m/min. The results indicate that ① the influence of partial denervation gradually extends over the whole muscle, and ② with running training, these changes occur more rapidly in partially denervated muscles.

29.25

FAST IIX AND SLOW MYOSIN EXPRESSION FOLLOW MITOCHONDRIAL INCREASES IN TRANSFORMING MUSCLE.
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The relationship between oxidative metabolism and myosin isoform expression in skeletal muscle is not known for fibers transforming from fast-to-slow type. Tibialis anterior muscles from female New Zealand white rabbits were stimulated continuously at 10 Hz for 4-21 days and muscle quantitatively analyzed for oxidative enzyme levels by histochemistry and for fast IIX and slow myosin mRNA distribution by in situ hybridization. Control muscle contained 6% slow but only 3% fibers coexpressed both slow and fast IIX myosin mRNA transcripts. Individual fibers from stimulated muscle transform at different rates. The increase in oxidative enzymes was detectable in many fibers by 4 days and preceded increases in appearance of IIX mRNA. Slow myosin transcripts were detected by 7 days in fibers with higher oxidative levels. Co-expression of IIX and slow transcripts peaked at 25% of fibers by 7 days. IIX then declined leaving slow myosin expressed in 65% of fibers by three weeks. We conclude that during fiber type transformation, individual fibers can transcribe two myosin mRNAs synchronously and that metabolic demand is an essential trigger for myosin switching. Supported by NIH HL 40880 and MDA.

29.26

COMPARISON OF FIBER SIZE AND CAPILLARITY IN PERFUSION FIXED AND FROZEN RAT SOLEUS MUSCLE.
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Shrinkage of skeletal muscle fibers following glutaraldehyde (GA) fixation and preparation for electron microscopy has been reported (Eisenberg and Mobley, Tiss. & Cell 7:383-387, 1975) and it has been suggested that fibers swell during freezing for histochemistry (Shorey and Cleland, Anat. Rec. 207:523-531, 1983). In order to correlate morphological with physiological measurements, it is important to know the effect of tissue preparation on variables such as fiber size and the visualization of capillaries. We compared fiber size and capillarity in the soleus muscle of Sprague Dawley rats (342-355 g, n = 6) after two routine procedures: 1) GA perfusion fixation and resin embedding (toluidine blue stained sections) and 2) freezing in liquid N_2-cooled isopentane followed by histochemical staining (PAS and alkaline phosphatase stained cryostat sections of the contralateral soleus stretched to the same length). Fiber cross-sectional area was approximately 33% less in resin (1587 ± 76 μm^2) than in frozen sections (2369 ± 80 μm^2). Capillary-to-fiber ratio was 12% lower in frozen tissue ($p<0.05$) and capillary number / fiber mm^2 was significantly greater in resin (1783 ± 92) than in frozen sections (1108 ± 27). Comparing sections fixed or not fixed with formalin vapor prior to thawing, we observed an increase in fiber cross-sectional area of about 10% without fixation, which contributes to the difference in fiber cross-sectional area between the two methods. In summary, more capillaries are identified in perfusion fixed samples and nearly a third of the difference in fiber area between the two methods is contributed to by fiber swelling when sections are thawed on glass slides. Supported by NIH grants HL 37387 and HL 17731.

29.27

MUSCLE FIBER CROSS-SECTIONAL AREA: COMPARISON BETWEEN FIXED AND FROZEN TISSUE.
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An issue which is still unresolved, is whether fixation and processing for electron microscopy (EM) result in muscle fiber shrinkage compared to frozen tissue processed for histochemistry. In a previous communication (*FASEB J.* 6: A960, 1992), we showed that there was no difference in fiber cross-sectional area (CSA) in adjacent samples of rat costal diaphragm which were immersion fixed and processed for EM (*Microvasc. Res.* 33: 98-117, 1987), or rapidly frozen and prepared for metachromatic histochemical staining (Ogilvie and Feeback, *Stain Technol.* 65: 231-241, 1990). However, when a similar study was conducted using hindlimb muscle samples, we found a significant ($p < 0.05$*) difference in fiber cross-sectional area (Δ area).

Muscle	n	Frozen (μm^2)	Fixed (μm^2)	Δ Area %
Extensor Digitorum Longus	4	2830 ± 159	2332 ± 165	-17.6
Flexor Digitorum Longus	2	1976 ± 176	1651 ± 205	-16.5
Plantaris *	5	3260 ± 147	2662 ± 59	-18.3
Soleus *	4	3864 ± 64	3225 ± 92	-16.5
Tibialis Posterior	1	2735 ± 161	2487 ± 127	- 9.1

We evaluated the potential role of sample sectional area, fiber type proportions and areas (types I, IIa,b,c) for each frozen sample, and possible differences in the sectioning angle between resin embedded and frozen tissue in causing these differences in measured Δ area. We found that none of the above variables could account for the Δ area. It remains to be determined whether the difference in CSA is the result of fiber swelling during freezing (Shorey and Cleland, *Anat. Rec.* 207: 523-531, 1983), or fiber shrinkage during fixation (Eisenberg and Mobley *Tiss. & Cell* 7: 383-387, 1975), or a combination of both. Supported by NIH Grant HL 17731.

29.28

FIBER CONVERSION IS DUE TO TRANSFORMATION, NOT REPLACEMENT, IN CHRONICALLY STIMULATED RAT MUSCLE.
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Chronic stimulation (CS) of rabbit fast-twitch muscle results in a progressive fast to slow fiber conversion via fiber transformation and replacement. The purpose of this study was to describe the effects of CS (10 Hz, 10 hr/d) for periods up to 61 d on the conversion process in rat fast-twitch extensor digitorum longus (EDL) muscle. During the early stimulation period (2-4 d) there was an increased incidence of basophilia (hematoxylin-eosin staining) and accumulation of RNA (acridine orange staining) predominantly in type IIB fibers. DNA replication and putative satellite cell activation were also evident, as indicated by ^{3}H-thymidine incorporation. By 12 d of CS, each of these variables had returned to control levels and there was no change in the fiber composition of EDL muscle. Following 28 d of CS, there was a decrease in the percentage of type IIB fibers (control 43 ± 3%; stim. 0 ± 0%) and an increase in the percentage of type IID fibers (control 30 ± 3%; stim. 60 ± 6%). There was no change in the percentage of type IIA (control 19 ± 3%; stim. 29 ± 4%) and type I (control 4 ± 1%; stim. 4 ± 1%) fibers. Further stimulation (61 d) resulted in the continued absence of type IIB fibers, a return to control levels of type IID fibers (control 30 ± 3%; stim. 23 ± 5%), and an increase in type IIA (control 22 ± 2%; stim. 45 ± 8%) and type I (control 4 ± 1%; stim. 8 ± 1%) fibers. Throughout each stage of CS, there was no histological evidence of fiber damage or necrosis. Contrary to the rabbit, these data indicate that CS-induced fiber conversion in the rat EDL muscle is entirely due to fiber transformation. Additionally, satellite cells appear to be either involved in the fast to slow transformation process or upregulated in response to the fibers' increased contractile activity and changing phenotype.

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MUSCLE FATIGUE

30.1

ENERGY COST OF CONTRACTION IS UNCHANGED IN RAT SKELETAL MUSCLE CHRONICALLY DEPLETED OF ATP AND CREATINE.
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Acute depletion of ATP has been shown to reduce the energy cost of contraction in rat gastrocnemius muscle. We examined the effect of chronic ATP and creatine depletion on contraction cost in rats fed 1% B-guanidinopropionate (B-GPA) for 8 weeks, which reduces fast skeletal muscle ATP content by 40-50% and total creatine by 80-90%. Using surface coil 31P-NMR acquisitions gated to brief bursts of contractions, we determined the phosphocreatine (PCr) cost of isometric twitches in controls (0.287 ± 0.023 µmol/g/twitch, SE, n=5) and ATP/creatine depleted muscles (0.288 ± 0.017). Tetanic contraction cost was likewise unchanged (2.25 ± 0.07 µmol/g/tetanus in controls vs. 2.30 ± 0.10 in GPA muscles). Denaturing SDS-PAGE analysis showed a transformation of myosin heavy chain distribution in the superficial gastrocnemius from 0/20/80 % type I/IIA/IIB in controls to 0/35/65 in GPA-fed animals. The condition that increases contraction economy in the acutely depleted muscles must therefore either be absent in the chronic case (e.g. elevated IMP), or is compensated for be gradual adaptations to the depleted phosphagen levels. (This work was supported by NIH Grant # 38972)

30.2

MODULATION OF THE ATP-SENSITIVE K+ channel (K+(ATP)) AND TETANIC FORCE BY TOLBUTAMIDE IN UNFATIGUED AND FATIGUED FROG SARTORIUS MUSCLES.
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The goal of this study was to determine if $K^+_{(ATP)}$ channels become active and affect the rate of fatigue development. In unfatigued, intact frog sartorius muscle fibers, 2 $mmole \cdot l^{-1}$ Tolbutamide, a K+(ATP) antagonist, produced a 10-15% decrease in tetanic force and had no significant effect on the action potential. When sartorius muscle fibers were fatigued in the absence of Tolbutamide with tetanic contractions at a rate of 1 contraction/sec, the tetanic force decreased by 88% over a 3 min period, while the width of the action potential increased by 45%. In the presence of 2 $mmole \cdot l^{-1}$ Tolbutamide the decrease in tetanic force was similar to the decrease observed in the absence of Tolbutamide. However, the increase in width of the action potential was larger; that is 1.3 msec to 2.1 msec, a 62% increase. Therefore, there is evidence for an activation of the $K^+_{(ATP)}$ channels during fatigue development, but the opening of these channels do not appear to affect force development. (Supported by NSERC and MRC of Canada)

30.3

THE EFFECT OF VOLUNTARY STRENGTH TRAINING ON THE CONTRACTILE PROPERTIES OF RAT SKELETAL MUSCLE.

Noel D. Duncan*, Alan Hayes*, Gordon S. Lynch*, Stephen H. Cody* and David A. Williams* (SPON: Mark Hargreaves), Muscle and Cell Physiology Laboratory, Dept. of Physiology, Univ. of Melbourne, Victoria 3052, Australia.

An animal model was devised that simulated strength training protocols commonly used by humans. Male Wistar rats aged 7 weeks (juvenile) or 13 months (adult) were trained to climb a 40cm vertical rack (3x6 repetitions, 4 days/week for 12 weeks) while carrying a load (comprising up to 120% of body weight) attached to their tails. Following training the EDL, soleus and biceps brachii muscles were ablated from the hindlimb and the isometric contractile force responses were recorded *in-vitro*. The adult trained group exhibited a longer TTP than the unexercised adult controls. In the EDL, P_0 was greater in the adult groups compared with the juvenile animals. P_0 of the soleus muscle was greater, and $^1/_2$RT longer in the adult trained group compared with unexercised controls. No significant changes in contractile properties were evident in the biceps brachii muscle. Strength-training did not affect fatigue-resistance except in the soleus muscle where it was significantly decreased in the juvenile rat group. No change in fibre type proportions of each muscle was evident following mATPase staining. The pH-sensitive fluorescent probe SNARF-1 in conjunction with laser-scanning confocal microscopy was used to investigate the degree of involvement of acidification in muscle fatigue. This was achieved by simultaneously determining force generation and intracellular pH in individual fibres which remained in the 3-dimensional syncytium of the intact muscle. The fatigue protocol induced little change in cytosolic pH in fibres of either EDL or soleus muscles.

Supported by the ARC, NH & MRC and NHF of Australia.

30.4

ELECTRICALLY ELICITED AND MAXIMUM VOLUNTARY POWER OUTPUT FOLLOWING FATIGUING EXERCISE IN HUMANS.

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In isometric contractions direct electrical stimulation has been used to confirm maximality of voluntary effort. In the present investigation we have adapted the technique to examine changes in power output consequent upon, and in recovery from, a fatiguing 25s maximum sprint performed on an isokinetic cycle ergometer at 60 rev/min (see Beelen & Sargeant, 1991, J. Appl. Physiol. 71 (6), 2332-2337). Before and after the sprint subjects allowed their legs to be passively turned by the motor driven cranks. During the passive movement the knee extensors were transcutaneously stimulated (4 pulses: 100Hz) generating peak stimulated power (PSP) at 90° past top centre. Maximum voluntary power (MVP) declined by 26 ± 5% during the sprint. PSP immediately after the sprint was reduced by 33 ± 8%. The time course of recovery of PSP was also similar to that for MVP (the latter was measured in a series of separate experiments): after 3 min they had recovered to 97 ± 5% and 98 ± 3% of control respectively. The close association between the changes in stimulated and voluntary maximum power suggest that our subjects were able, voluntarily, to full activate their muscle in this complex multi-joint movement.

30.5

SMOKING CESSATION AND EXERCISE TIME TO FATIGUE.

Rex A. Holland, Eric B. Van Walleghem and George D. Swanson. The Pacific Wellness Institute and Department of Physical Education, California State University, Chico, CA 95929.

The purpose of this study was to determine the effect smoking cessation has on exercise time prior to muscle fatigue during high-intensity arm ergometry. Six healthy, physically fit male smokers, between the ages of 20 and 23 volunteered to participate in this investigation. The testing was performed over a 3 week period with 5 tests performed per week. Subjects were allowed to smoke on weeks 1 and 3, but were required to abstain from smoking on week 2. The testing apparatus was a mechanically braked arm ergometer. During the week, each subject performed timed arm cranking bouts at 60, 120, 180, 240 and 300 W. Subjects were required to maintain an arm cranking frequency of 60 RPM. When muscular fatigue impaired a subject's ability to maintain this cadence, the test was terminated. At each work load, the subject's exercise times during weeks 1 and 3 were compared to their exercise time in week 2. The results indicate that smoking cessation increases subjects exercise time prior to fatigue (120 W, 83 ± 38 sec; 180 W, 22 ± 9 sec; 240 W, 8 ± 3 sec; 360W, 8 ± 3 sec). All subjects performed the 60 W exercise for 20 minutes without appreciable fatigue whether smoking of not. These findings should have major implications in the work force and recreational settings where the early onset of muscular fatigue may effect performance, productivity, and enjoyment.

30.6

EFFECT OF PRIOR LEG EXERCISE ON HIGH-INTENSITY ARM ERGOMETRY.

George D. Swanson, Rex A. Holland and Eric B. Van Walleghem. The Pacific Wellness Institute and Department of Physical Education, California State University, Chico, CA 95929.

For high-intensity exercise, the exercise time (t) prior to exhaustion is inversely proportional to the applied power (P) as characterized by a rectangular hyperbola: (P-Pc) t=W' where Pc is termed the critical power for the upper limit of sustainable power and W' characterizes the work that can be done prior to exhaustion above Pc. The purpose of the present study was to determine the parameters (Pc, W') for the arms under high-intensity arm exercise conditions with and without prior exhaustive leg exercise, (210 watts to exhaustion followed by a six minute recovery time). Nine healthy, physically fit male subjects volunteered to participate in this investigation. The testing apparatus was a mechanically braked arm ergometer. On a given week, each subject performed timed arm cranking bouts at 60, 120, 180, 240 and 300 watts. Each test was performed on a different day in a random-like manner. All subjects were capable of performing the 60 watt test for 20 minutes without appreciable duress. Thus, only the four higher work rates were used to estimate the hyperbola parameters. The results indicate that prior exhaustive leg exercise diminishes W' (mean decrease = 2350 Joules, $p< 0.01$) with a variable, but minimal (non-significant) change in Pc. This suggests that prior exhaustive leg exercise diminishes the high-intensity energy stores of the arms.

30.7

RECOVERY OF THE RESTING MEMBRANE POTENTIAL (Vm) AND INTRACELLULAR POTASSIUM [K+]i FOLLOWING FATIGUE.

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The loss of K^+ from skeletal muscle and its accumulation in the interstitial space has been hypothesized to lead to a decreased excitability of the sarcolemma which contributes to the development of fatigue. We have used microelectrodes to determine Vm and [K+]i in single muscle fibers from the semitendinosus of *Rana pipiens* and to characterize the time course of recovery after fatiguing stimulation (100 ms trains at 150 Hz, 1/sec for 5 min). This stimulation protocol decreases peak tetanic tension (Po) to 10% of its initial value and allows an initial fast recovery phase to 25% of Po in 2 min and a second slower phase to 90% of Po by 40 min. The ion selective microelectrodes (ISME) were constructed using a K^+ selective resin cocktail (Fluka #60398). ISMEs were calibrated in 50-200 mM K^+ solutions before and after each experiment. Resting Vm and [K+]i in 7 fibers were -80.14±2.52 mV and 143.14±9.48 mM. At fatigue Vm fell to -73.70±1.63 mV and [K+]i to 72.85±13.70 mM. Within 10 min Vm recovered to -80.43±2.38 mV, with a time constant of 2.12±0.87 min, while [K+]i recovered to 142.43±7.58 mM, with a time constant of 1.84±0.62 min. Although both Vm and [K+]i recovered faster than force this does not discount K^+ induce depolarization as a factor in the fast phase of recovery. Furthermore, it is not known how K^+ changed in the transverse tubules. +Supported by the M.U. Schmitt Fellowship.

30.8

THE EFFECT OF CHANGES IN $H_2PO_4^{-1}/HPO_4^{-2}$ ON MAMMALIAN SKELETAL MUSCLE FORCE PRODUCTION.

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To test the hypothesis that the inorganic phosphate (Pi) induced depression of force generation in fast and slow twitch mammalian skeletal muscle is the result of an increasing percentage of diprotonated Pi ($H2PO4^{-1}$) we used mouse extensor digitorum longus (EDL) and soleus (SOL) contracting at 70Hz and 50Hz respectively for 500ms once per 90 sec in Krebs-Henseliet solution containing 20mM Pi at 27°C. The pH was adjusted to 7.2, 6.7 or 6.4 resulting in $H_2PO_4^{-1}/HPO_4^{-2}$ values of 0.4, 1 and 2.6. When compared with pH altered solutions but no Pi, SOL force development was not effected until $H_2PO_4^{-1}/HPO_4^{-2}$ was greater than 1 where there was a pH independent depression. The absolute difference between Pi and pH did not change over time. On the other hand EDL force development was depressed with either a Pi ratio greater or less than 1 but with different patterns. HPO_4^{-2} had no initial effect but over 24 contractions decreased force significantly over and above pH. $H_2PO_4^{-1}$ showed a larger decrease in force over 5 contractions than that of simply pH alone. This difference between Pi and pH decreased until after 25 contractions it was zero. Therefore, with a constant Pi concentration, an increased $H_2PO_4^{-1}/HPO_4^{-2}$ ratio resulted in a depression of both fast and slow twitch muscle. Only fast twitch was effected by a decreased $H_2PO_4^{-1}/HPO_4^{-1}$.

Supported by NSERC Canada.

30.9

MYOSIN HEAVY CHAIN PHENOTYPE CORRELATES WITH DIAPHRAGM FATIGUE RESISTANCE IN RATS UNDERNOURISHED DURING PRE AND POSTNATAL DEVELOPMENT.

Beverly S. Brozanski*, Monica Daood*, Robert D. Guthrie, and Jon F. Watchko. University of Pittsburgh Sch. of Med., Pittsburgh, PA 15213

Undernutrition during pre- and postnatal development is associated with an alteration in the myosin heavy chain (MHC) phenotype of the rat diaphragm (DIA) as demonstrated by: 1) an increase in the proportion of MHC neonatal and MHC slow, and 2) a decrease in the proportion of MHC 2B and MHC 2X, in the DIA from undernourished (UN) rats when compared to controls (CTL) (Brozanski et al, Pediatr Res 31:302A, 1992). We correlated the MHC phenotype (as indexed by a ratio of fast MHC isoform [MHC 2A + MHC 2X + MHC 2B] to the developmental MHC isoform content [MHC slow + MHC neonatal]) with the fatigue resistance (FR) of the costal DIA from UN and CTL rats from birth through postnatal day 60. FR was measured during isometric contractions using the Burke fatigue test. *In the immediate* postnatal period, FR was high and comparable in the UN group when compared with the CTL. Beyond the first week of life, FR declined but was consistently higher in the UN animals when compared with the CTL. There was a direct correlation between FR and the MHC phenotype of the muscle (r^2=0.86). We conclude that the FR of the DIA during development is a function of the energetic demands of the contractile proteins, as reflected its MHC isoform composition.

Supported by NIH HL 02491 and the American Lung Association.

30.10

REDUCED PHOSPHORYLATION OF MYOSIN LIGHT CHAINS IN FATIGUED SKELETAL MUSCLE.

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Fatigued rat fast-twitch muscle reaches a peak of staircase later when fatigued than when rested. This study was done to see if phosphorylation of the regulatory light chains (P-LC) a possible mechanism of potentiation, was also slowed in fatigue. The gastrocnemius muscles of anesthetized rats were isolated *in situ* stimulated for 5 minutes at 10 Hz. Following 20 minutes of recovery, muscle was quick-frozen after 0, 5, 10 or 20 s of 10 Hz stimulation. Control (rested) muscles were frozen at similar times, without fatigue. The developed tension (% potentiation) and phosphorylation of P-LC (% phosphorylated).

time of 10 Hz (s)	0	5	10	20
CONTROL: Potentiation	0	71 ± 4	87 ± 3	49 ± 12
P-LC	10 ± 4	38 ± 7	60 ± 6	80 ± 9
FATIGUED:Potentiaion	0	48 ± 8	79 ± 6	86 ± 14
P-LC	3.2 ± 1.2	8 ± 4	11 ± 3	19 ± 5

A computer simulation of P-LC phosphorylation demonstrates that similar phosphorylation can be achieved by much smaller Ca^{2+} transients, or with severe inhibition of the enzyme (myosin light chain kinase), which is responsible for the phosphorylation reaction.

Supported by grants from NSERC.

30.11

CORRELATION BETWEEN MUSCLE RELAXATION AND SARCOPLASMIC RETICULUM CA^{2+}-ATPASE DURING ELECTRICAL STIMULATION TO FATIGUE.

Michel C. Biedermann and Gary A. Klug. Univ. of Oregon, Eugene, OR 97403

Prolonged muscle activity depresses Ca^{2+} uptake and release by sarcoplasmic reticulum (SR). The purpose of this study was to investigate the relationship between the SR Ca^{2+} uptake (CU) and the mechanical events in rat gastrocnemius muscle following electrical stimulation (20Hz @ 37°C) for 1 - 60 min. Half-relaxation time ($RT_{½}$), and maximum rate of relaxation (*RR*) were correlated with the initial rate of CU measured in crude muscle homogenates. After 1', $RT_{½}$ had increased by 74% over control, whereas RR decreased by 58%. These events were accompanied by a 14% reduction in CU. By 10', $RT_{½}$ and CU had returned to normal whereas RR remained depressed by 75%. At 60', $RT_{½}$ was not different from normal values, but RR and CU were depressed by 55% and 27% respectively. It is apparent from these data that a close correlation does not always exist between SR Ca^{2+}-uptake and various parameters that are commonly used to define the ability of muscle to relax.

Sponsored by NIH GM 07257 and by NIH AR 39583.

30.12

POST EXERCISE RECOVERY OF SARCOPLASMIC RETICULUM FUNCTION.

K. A. Luckin*, S. B. Smulovitz*, and G. A. Klug. Univ. of Oregon, Eugene OR 97403

The purpose of this study was to determine if the post-exercise depression in sarcoplasmic reticulum (SR) Ca^{2+} fluxes are reversible and to ascertain if the recovery process could be correlated with events in the Ca^{2+}-ATPase catalytic cycle. Male Sprague-Dawley rats (280-300g) were randomly assigned to one of 5 groups (n=4): control, exercise (100' at 70% MVO_2), or 1 hour, 2 hour, or 3 hour recovery. SR from each group was isolated from the deep red portions of the gastrocnemius muscle. Initial rates of Ca^{2+} uptake and release (initiated with 10 μM $AgNO_3$) were measured using a Ca^{2+}-sensitive mini-electrode at initial activator Ca^{2+} and ATP concentrations of 0.02 and 1 mM. Ca^{2+}-stimulated phosphoprotein formation was measured on glass fiber filters by incorporation of γ-^{32}P ATP (5 μM) into SR protein. Ca^{2+}-ATPase activity was determined using the enzyme-linked optical assay.

Recovery Group	ATPase (μmol/min*mg SR)	^{32}P Incorp. (nmol/mg SR)	Ca^{2+} Uptake (nmol/sec*mg SR)	Ca^{2+} Release (nmol/sec*mg SR)
Control	1.28 ± .07	0.36 ± .02	5.5 ± .25	4.0 ± .14
No Recovery	0.55 ± .06†	0.25 ± .01†	2.5 ± .24†	2.2 ± .70†
1 Hour	1.27 ± .20	0.37 ± .03	4.1 ± .17†	3.9 ± .32
2 Hour	1.15 ± .14	0.37 ± .04	6.3 ± .24	3.4 ± .30
3 Hour	0.87 ± .13†	0.33 ± .01	5.5 ± .54	3.4 ± .30

† p<0.05 to control

SR from exercised animals showed depressions in ATPase activity, phosphoprotein formation, and initial rates of Ca^{2+} uptake and release when compared to control SR. The reversal of this depression in every case except Ca^{2+} uptake was complete within one hour of rest. The rate of Ca^{2+} uptake returned to control values by 2 hours of recovery. These findings suggest that the function of SR is markedly compromised after a single bout of submaximal prolonged exercise but that this impairment is a reversible process requiring 2 hours to fully recover. The data also imply that the depression and recovery of uptake and ATPase activity are linked to the capacity to carry out the obligatory phosphorylation of the ATPase protein during the catalytic cycle.

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30.13

THE RELATIONSHIP BETWEEN WORK RATE AND THE INTENSITY OF DISCRIMINABLE SENSATIONS ACCOMPANYING MUSCULAR WORK

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Any of a number of discriminable sensations associated with muscular work may ultimately limit exercise performance due to an inability to tolerate increases in sensory intensity. The relative magnitudes of these sensations during exercise are not known. The intensities of leg effort, muscle tension, muscle discomfort, muscle pain and breathing discomfort were compared (n=13) using the Borg scale at 6 work rates of 15s duration (20-120% maximum power output using incremental cycle ergometry, MPO) on two occasions. Each sensation was rated separately. Sensation magnitudes are shown in the table (mean, SD).

	20%MPO	40%MPO	60%MPO	80%MPO	100%MPO	120%MPO
EFFORT	0.6(0.7)	1.5(0.8)	2.5(0.8)	3.5(1.0)	4.6(1.3)	5.9(1.6)
TENSION	0.5(0.4)	1.3(0.7)	2.3(0.9)	3.4(1.0)	4.3(1.2)	5.2(1.7)
DISCOMFORT	0.3(0.4)	0.7(0.7)	1.5(1.2)	2.5(1.3)	3.5(1.5)	4.0(1.6)
PAIN	0.1(0.3)	0.2(0.4)	0.6(0.8)	1.0(1.0)	1.9(1.4)	2.3(1.7)
BREATH.DISC.	0.2(0.4)	0.5(0.5)	0.7(0.9)	1.0(0.8)	1.5(1.2)	1.8(1.2)

The magnitude of leg effort exceeded that of all other sensations under these conditions. However, the specific sensation that ultimately reaches intolerable magnitude and results in cessation of muscular work may be dependent upon the characteristics of the work performed.

30.14

RELATIONSHIP OF RESPIRATORY MUSCLE FATIGUE RESISTANCE TO SDH ACTIVITY AND MYOSIN HEAVY CHAIN PHENOTYPE DURING POSTNATAL DEVELOPMENT.

Jon Watchko, Molly Daood, Robert Guthrie, and Gary C. Sieck. Univ. of Pittsburgh Sch. Med, Pittsburgh, PA 15213, and Mayo Clinic, Rochester, MN 55905.

We correlated the fatigue resistance [FR] of the costal diaphragm (DIA) and the external abdominal oblique (EAO) muscles during postnatal development, with their respective 1) oxidative capacities (indexed by quantitative measures of succinic dehydrogenase [SDH] enzyme activity) and, 2) myosin heavy chain (MHC) phenotypes. FR was measured during isometric contractions using the Burke fatigue test. FR of the DIA and EAO was high in newborns and declined during postnatal development. SDH activity was uniformly low in neonatal DIA and EAO and increased with development. Thus, FR did not correlate with SDH activity (r^2 = 0.005). In contrast, FR did relate to 1) the MHC phenotype as indexed by the ratio of adult MHC isoform content ([slow]+[2A]+[2X]+[2B]) to developmental MHC isoform content ([slow]+[neonatal]) (r^2 = -0.64) and 2) the ratio of [SDH] to [MHC phenotype] (r^2 = 0.95). We conclude that FR of respiratory muscle during development relates to a balance between the muscles oxidative capacity and the energetic demands of its contractile proteins as reflected by MHC isoform composition.

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30.15

CAFFEINE AND NEUROMUSCULAR FUNCTION IN HUMANS: NO EFFECTS OF TOLERANCE. M. Tarnopolsky, A. Hicks, C. Cupido, and A.J. McComas. McMaster University, Hamilton, Ont., CANADA, L8N 3Z5.

Caffeine increases the force of muscular contraction during low frequency stimulation by potentiating Ca^{++} release from the sarcoplasmic reticulum. Tolerance to the metabolic effects of caffeine has been reported but the neuromuscular effects have not been examined. Twelve healthy male subjects were classified as habitual (HAB; n=6) or non-habitual (NONHAB; n=6) caffeine consumers based upon 4 day diet record analysis. The mean caffeine consumption for HAB was 771 mg/d and for NONHAB was 14 mg/d. Subjects were randomly allocated to receive caffeine (6mg/kg) or placebo (citrate) in a double-blind fashion, 100 min prior to a 2 min stimulation of the common peroneal nerve in a custom made dynamometer (2 trials X 20 Hz; 2 trials X 40 Hz). Maximal voluntary contraction strength (MVC) was measured before and after (+2s and +15 min) the stimulation protocol. Torque was measured every 30s during the stimulation protocol and at +1, +5 and +15 min. Caffeine potentiated the force of contraction at each time point during the 20 Hz stimulation ($P<0.05$) with no effect of habituation. There was no effect of caffeine on 40 Hz stimulation strength nor was there an effect on MVC. It was concluded that caffeine potentiates 20 Hz strength during fatigue but there are no effects of tolerance.

SKELETAL MUSCLE DAMAGE

31.1

EFFECT OF EXERCISE-INDUCED MUSCLE DAMAGE ON SERUM INTERLEUKIN-6 LEVELS. K.L. Woolley[1], M.J. Woolley[1*], N.L. Jones[1], G.J. Heigenhauser[1] and J. Gauldie[2]. Departments of Medicine[1] and Pathology[2], McMaster University, Hamilton, Ontario, Canada, L8N 3Z5.

Increased serum interleukin-6 (IL-6) has been reported after prolonged exercise. Whether this increase is due to muscle damage that may occur with prolonged exercise is not clear. We examined the effect of exercise-induced muscle damage on serum IL-6. Six, healthy, non-weight trained males (mean ± sd: age 29 ± 2.7 yrs; ht 175 ± 8.0 cm; wt 68 ± 13.1 kg) completed an exercise and control day (6 wks apart) in a randomized, counter-balanced order. On the exercise day, subjects did 4 weight training exercises. For each exercise, 4 sets of 10 repetitions (concentric phase 3 sec., eccentric phase 10 sec.) were completed at 80% of the subject's pre-determined one repetition maximum. On the control day, subjects rested. Muscle damage was assessed using serum creatine kinase measures and muscle soreness ratings (Borg scale). Creatine kinase was measured before, immediately after and 2, 6 and 24 hrs after exercise. Muscle soreness was evaluated before, 24 and 48 hrs after exercise. Serum IL-6 was measured before, immediately after and 2, 6 and 24 hrs after exercise or rest. Weight training induced muscle damage, as indicated by a significant increase ($p < 0.05$) in creatine kinase ($\mu mol.min^{-1}.l^{-1}$: pre-ex = 56.6 ± 29.61; 24 hrs post-ex = 173.8 ± 72.37, n=4) and muscle soreness ratings (pre-ex = 0 ± 0.0; 24 hrs post-ex = 3 ± 1.9). IL-6, measured with a sensitive (10 $pg.ml^{-1}$) bioassay, was not detected in exercise or control samples. These findings suggest that exercise-induced muscle damage may occur without a detectable increase in circulating IL-6.

31.2

MUSCLE CELL DEATH FOLLOWING ECCENTRIC EXERCISE. Daniel Karapondo*, R. Conatser, G. Chleboun and J. N. Howell. Somatic Dysfunction Res. Inst., Ohio Univ., Athens, OH 45701

Following eccentric exercise of human elbow flexors to failure under heavy load (90% of isometric max. determined at elbow angle = 90°), isometrically measured muscle strength fell by 44% (N=34) and recovered slowly (50% recovery in 2 wks.). Soreness resulting from the exercise lasted only 5 days. Following the exercise, the IEMG amplitudes associated with submaximal (<20%) isometric contraction increased 2 to 3 fold, indicating the presence of muscle fibers capable of generating action potentials, but compromised in their ability to generate force. The ratio of EMG amplitude to force output in submaximal contractions returned to normal within 3 days, during which time no significant recovery of isometric, maximal force occurred. A significant correlation was observed between the extent of strength loss and the decrease in the force/EMG ratio.

Taken together with biopsy data from other labs, these observations indicate that injured fibers, which are still capable of generating action potentials, but unable to generate much force, become electrically inexcitable within 3 days after the exercise, probably because of the death of these cells. Recovery of muscle strength, which occurs much later, presumably requires regeneration of new cells. (Supported by the American Osteopathic Association.)

31.3

EXCITATION-CONTRACTION COUPLING LOSS IN ECCENTRIC CONTRACTION-INDUCED MUSCLE INJURY. G. Warren, D. Lowe, D. Hayes*, B. Prior, C. Karwoski*, and R. Armstrong. The University of Georgia, Athens, GA 30602

The objective of this study was to determine if a loss of excitation-contraction coupling contributes to the reduction in maximal isometric tetanic force (P_o) occurring in eccentric contraction-induced muscle injury. Mouse soleus muscles were isolated, placed in an oxygenated Ringers, and P_o was measured. Each muscle performed one of four contraction protocols: 1) no contractions (NO); 2) 20 isometric (20 ISO); 3) 10 eccentric (10 ECC); or 4) 20 eccentric (20 ECC). Muscles were set to 0.9 L_o and stimulated at 200 Hz for 167 ms with 3 min between contractions. Eccentric contractions were performed using a lengthening velocity of 1.5 L_o/s and a length change of 0.25 L_o. Following the protocol, P_o at L_o was measured and 3 min later, force was measured upon addition of 50 mM caffeine.

Protocol	Decline in P_o (%)	Caffeine force (% final P_o)
NO (n = 6)	---	74.7[a] (SE = 1.0)
20 ISO (n = 10)	3.8[a] (SE = 2.4)	71.8[a] (SE = 2.1)
10 ECC (n = 12)	19.9[b] (SE = 2.3)	80.2[b] (SE = 1.6)
20 ECC (n = 10)	42.6[c] (SE = 4.2)	118.4[c] (SE = 8.5)

Values with the same letter are not significantly different ($\alpha = 0.05$).

In conclusion, excitation-contraction coupling loss is probable since the 20 ECC muscles produced less force during electrical stimulation than during exposure to caffeine.

31.4

A SYSTEMS MODEL OF EXERCISE-INDUCED ELEVATED SERUM CREATINE KINASE. E.W.Banister, D.Dray*, and Y.Fukuba*. Simon Fraser University, B.C.Canada V5A 1S6.

The purpose of this study was to develop a systems model of the relationship between the time course of elevated serum enzyme activity (ESEA, Total CK) in the vascular space. A coherent, quantitative model of enzyme flux from injured muscle must consider and account for the described features of the empirical ultrastructural and biochemical changes producing it. The model proposed here defines 3 rate constants ($k_1 > k_2 > k_3$) controlling pore development in the muscle cell membrane producing enzyme loss to the interstitial and vascular space, pore closing or healing, and final degradation of enzyme from the vascular space, respectively. The time course of ESEA in the vascular space is given by: $x_3(t) = ak_1k_2\,[Ae^{-k_1t} + Be^{-k_2t} + Ce^{-k_3t}]$ where: $A = +1/(k_1-k_2)(k_1-k_3)$, $B = -1/(k_1-k_2)(k_2-k_3)$, $C = +1/(k_1-k_3)(k_2-k_3)$. This equation describes cellular enzyme loss from a focal point in the muscle and total enzyme loss at any time (t) is the sum of such loss from each focus where the onset of loss from each site is separated from other sites by a time delay (t d)) depending on the extent of focal damage in the locale. ESEA (total CK) was measured in 5 male subjects immediately before and serially every 5hr throughout a period of 40hr and every 15hr thereafter through 240hr until recovery of ESEA to baseline after their completing 70 eccentric quadriceps contractions in 20 min. Iterative modeling of predicted ESEA to its empirical serial value to minimize the sum of squared differences resulted in R squared values greater than 0.9 in all subjects and low none directional residuals. Even a large area CK time course in 2 subjects, indicative of extensive micro-muscle injury, were well fitted by the model. Insight into the time course of an initial event inducing ESEA is provided by the model in that its rate constant must be greater than the modeled value of k_1. Supported by NSERC grant to EWB

31.5

ULTRASTRUCTURAL DISRUPTION ACCOMPANYING ENDURANCE TRAINING. K. Whittal and W.S. Parkhouse. Kinesiology, Simon Fraser University, Burnaby, B.C., Canada V5A 1S6

The effect of continuous (CT) and oscillatory training (OT) on muscle ultrastructure was examined in female Sprague Dawley rats. The continuous trained (CT) rats were subjected to a progressive treadmill training regime for a total of 15 weeks with the final workload being: 32.5 m/min; 60 min. duration; 8% incline; 5 times per week. The oscillatory trained (OT) animals did the same training regime for the first 12 weeks. During the last three weeks they alternated 5 min of high with 5 min of low intensity running. Mean velocity and total distance covered were identical to the CT group. Twenty four hours after the last bout of exercise the plantaris, soleus and heart were removed and prepared for electron microscopy. Isolated myofibrils from the plantaris muscle were further examined by SDS PAGE. EM revealed disruption of the sarcotubular system and damage to the mitochondria with no difference being observed between training programs. In contrast, SDS PAGE suggested an enhanced degradation of myofibrillar proteins with OT. Degradation of cytoskeletal proteins appeared to be selective (ie.α-actinin) whereas most regulatory proteins were degraded under both training regimes. Subsequent exercise performance does not appear to be impaired by this training induced muscle damage.

This work was supported by a NSERC grant to WSP.

31.6

TIME COURSE OF MUSCLE TORQUE, DELAYED ONSET MUSCLE SORENESS, AND MUSCLE DAMAGE FOLLOWING ECCENTRIC EXERCISE. Donna MacIntyre, W. Darlene Reid, Donald C. McKenzie. School of Rehab. Med. and Family Practice, University of British Columbia, Vancouver, B.C.

The purpose of this study was to examine the time course of muscle torque, delayed onset muscle soreness, and indicators of muscle damage (DOMS) in response to two intensities of fatiguing eccentric contractions. Using a randomized cross-over design, subjects (n=19) were either assigned to perform a mild or severe intensity of fatiguing eccentric contractions on the KinCom dynamometer. Tests included eccentric muscle torque, DOMS questionnaires, and serum levels of creatine phosphokinase (CPK) at the following intervals: before fatiguing exercise, 24 hours, 48 hours, 4 days and 7 days. Muscle torque was tested using the same type of contraction, velocity, ROM as that of the fatiguing exercise. DOMS was analyzed using the visual analogue scale and descriptor differential scale. Not less than 12 weeks after the first phase, subjects repeated the same protocol at the other intensity. Both torque and DOMS worsened at 24 hours, did not change between 24 and 48 hours and then improved until 7 days. Although CPK tended to increase after the fatiguing exercise, there were no significant changes during the time intervals tested. *Supported by B.C. Health Research Foundation and Canadian Fitness and Lifestyle Research Institute*

31.7

SATELLITE CELL ACTIVATION FOLLOWING AN ACUTE BOUT OF DOWNHILL RUNNING IN TRAINED AND UNTRAINED RATS. Julie A. Opiteck*, Christine A. Viguie* and Timothy P. White. University of Michigan, Ann Arbor, 48109 and University of California, Berkeley 94720.

A single bout of exercise that favors lengthening contractions can produce muscle fiber damage and initiate repair responses. We hypothesized that following an acute bout of downhill running, muscles of rats exposed to a training program of predominantly lengthening contractions would exhibit significantly less damage and satellite cell activity than muscles of untrained rats. Adult male Sprague-Dawley rats were run trained downhill for 8 wks on a treadmill; -18 degree slope, 30 min/day, 5 days/wk, 15 m/min. One to two days after the training program, trained (n=9) and age-matched untrained (n=5) rats underwent a single 60 min downhill run at 15 m/min, -18 degree slope. Muscles were excised 48 hrs thereafter. One hour prior to myectomy rats were injected with 5-bromo-2'-deoxyuridine (BrdU) to label mitotically active satellite cells. For medial tricep and soleus muscles the number of damaged fibers per 500 fibers was 8.3 $\pm$ 1.7 and 13.3 $\pm$ 0.3 (mean $\pm$ SE) for trained and 20.3 $\pm$ 4.3 and 37 $\pm$ 3 for untrained rats, respectively. In soleus muscles, satellite cell activity was also greater in untrained (25.2 $\pm$ 3.6 activated satellite cells per 1,000 myonuclei) than in trained rats (6.1 $\pm$ 1.1). Thus, lengthening contraction biased training of sufficient intensity and duration can prevent significant muscle fiber injury and subsequent satellite cell activity. Supported by NIH DE-07687 and AG-00114.

31.8

BROMELAIN DOES NOT AFFECT MALONALDEHYDE PRODUCTION AFTER CONTRACTION-INDUCED MUSCLE INJURY. H. Burton, J. Walker,* F. Cerny, P. Horvath. SUNY @ Buffalo, Buffalo, NY 14214.

Bromelain, a proteolytic enzyme with anti-inflammatory properties, attenuates the development of contraction-induced skeletal muscle injury. Oxygen free radicals, produced during the "inflammatory" stage of muscle injury, have been purported to be a significant contributor to cell membrane breakdown. We have shown a transient increase in levels of muscle malonaldehyde (MA), a primary product of lipid peroxidation, 24 h after lengthening contractions. The purpose of this study was to investigate the effect of bromelain on MA production in rat extensor digitorum longus (EDL) muscles, injured by lengthening contractions. EDL muscles were injured bilaterally using a motorized foot pedal which flexed/extended the foot repeatedly while the muscle was electrically stimulated during extension. Bromelain was administered orally at 12 h intervals beginning 12 h before injury. Twenty-four h post-injury, malonaldehyde levels of 109.1 $\pm$ 6 and 105.5 $\pm$ pmol/mg protein in untreated and treated groups, respectively, were significantly higher than the value of 86.4 pmol/mg in controls ($p < 0.05$). There was no difference between experimental groups. Thus, bromelain does not appear to attenuate lipid peroxidation following contraction-induced muscle injury.

31.9

DAMAGE IN SELECTED SKELETAL MUSCLES OF RATS AFTER UPHILL AND DOWNHILL RUNNING. J. Komulainen*, J. Kytölä* and V. Vihko* (SPON: H. Suominen). LIKES-Res. Ctr., Univ. Campus, Jyväskylä, SF-40100, Finland

Prolonged submaximal running of unaccustomed rodents results in delayed damage in certain skeletal muscles. The degree of this necrotic "exercise myopathy" is dependent on e.g. muscle in question, fiber type, and type and duration of exercise applied. After eccentrically biased exercise the damage is more serious than after concentrically biased exercise.

In order to study the contribution of muscle swelling (water content) to exercise myopathy, two types of running exercises were performed. As a marker of muscle damage ß-glucuronidase activity (ß-GUase) together with light microscopy were used. Male rats, aged 20 weeks, were made to run on a treadmill at a speed of 16 m x min^{-1} for 90 min on uphill (U,13,5°) or downhill (D,13,5°) tracks. Groups of animals together with sedentary controls were killed 2, 12, 48, and 96 h after cessation of exercise and samples from m. soleus (MS), the red parts of m. quadriceps femoris (MQF), m. vastus lateralis (MVL), and the outer part of m. triceps brachii (MTB) were analysed for water content (% W) and ß-GUase. M. gastrocnemius (MG) was analysed for ß-GUase.

% W in MS increased 2 h, in MQF 12 h, and in MVL 96 h after U. In D the % W increased in MS 12 h, and in MQF and MVL 2 h afterwards. These values remained high for 96 h after both exercises. In MTB no changes occurred. The increased activity of ß-GUase and histological studies showed exercise myopathy in MS 48 h after both U and D and in MQF 48 h and in MVL 96 h after D. % W and ß-Guase in MQF 48 and 96 h, and in MVL 12 and 96 h after D were higher than after U. Thus MS and MG were more strongly damaged after U and MQF and MVL after D.

The results show that exercise myopathy and it's degree is dependent on the increase of muscle water content and on the contracting conditions of the muscle in question.

31.10

DO SERUM CREATINE KINASE AND CARBONIC ANHYDRASE III REALLY REFLECT EXERCISE-INDUCED MUSCLE DAMAGE? V. Vihko*, T. Takala* and J. Komulainen* (SPON: H. Suominen). LIKES-Res. Ctr., Univ. Campus, Jyväskylä, SF-40100, Finland

The release of certain muscle proteins, such as creatine kinase (CK) and carbonic anhydrase III (CA III), to serum after exercise is widely used to estimate the magnitude of muscle damage. For instance, serum creatine kinase increases have been reported to be different after eccentrically compared to concentrically biased exercise.

Male rats, aged 20 weeks, were made to run at a speed of 16 m x min^{-1} for 90 min uphill (13,5°) or downhill (13,5°), blood samples were taken 2, 12, 48, and 96 h after the exercises and analysed for serum CK activity and CA III concentration.

CK was significantly elevated 2 h after both types of exercises and the level was the same as in controls 96 h afterwards. The highest (n.s.) concentrations of CA III were observed 12 h after both exertions. 48 h and 96 h post-exercises the concentrations were similarly below the control level

Studies on selected skeletal muscles of the same animals showed severe exercise myopathy 48 h after the exertions The increases in the two serum proteins determined are not in accordance with the necrotic phase of the myopathy but occur much earlier, probably already during exercise. We therefore suggest that in unaccustomed exercise the immediate rise after exertion in serum muscle proteins is mainly caused by increased lymphatic drainage.

31.11

EFFECT OF MUSCLE DAMAGE ON EMG ACTIVITY DURING DYNAMIC AND STATIC CONTRACTIONS. S. Hasson and J. Williams. Texas Woman's University, Houston, TX 77030

14 subjects were evaluated for magnitude (root mean squared RMS) and frequency (mean power-MPF) of EMG during max concentric (CON), eccentric (ECC) and isometric (MVC) contractions of the quad. Subjects also performed a 70% MVC to fatigue, while RMS, MPF and RPE were assessed at 10-sec intervals. EMG collection was over the distal head of the v. medialis. Subjects then performed a stepping protocol of 10-min (left leg-eccentric) to induce muscle injury and soreness. Subjects returned at 24 and 48-hrs and all measures were repeated. RMS was higher ($p<0.05$) for ECC and MVC compared to CON (18 and 24%). MPF was higher ($p<0.05$) for CON compared to ECC (80.0 vs 69.9 Hz). There was no difference between days for RMS and MPF. RPE and MPF had a negative correlation ($r=-0.72$), while RPE and RMS had a strong correlation ($r=0.91$). The highest correlations existed at baseline and 48-hrs (RPE-MPF, $r=-0.70$ and $r=-0.84$; RPE-RMS, $r=0.93$, 0.98), while at 24-hrs (time of lowest torque, fastest time to fatigue and greatest muscle soreness) the poorest relationships existed (RPE-MPF, $r=-0.61$; RPE-RMS, $r=0.80$). It appears that ECC action evokes a greater electrical response, but at a lower frequency than CON action. The relationship of RPE and EMG parameters during a fatiguing bout are strongly related when muscle soreness is not present. This relationship of RPE-EMG may aid in clinically assessing muscle fatigue and exertion.

31.12

COMPARISON OF MUSCLE INJURY ASSOCIATED WITH HIGH-RESISTANCE ECCENTRIC EXERCISE IN YOUNG AND OLD RATS. Todd McBride and Richard Carlsen. U of California, Davis, CA 95616

We have employed the weight-lifting model introduced by Wong and Booth (J.Appl.Physiol.65:950) to investigate the effect of eccentric, high-resistance exercise on tibialis anterior (TA) muscles in young (6 months) and old (32 months) Fisher/BN 344 rats. Our hypothesis states that the aged rats will experience more extensive muscle injury and a greater impairment of contractile function after 1 or 2 bouts of exercise than will the young adult rats. The anesthetized rat is stimulated to unilaterally contract both ankle extensors and flexors by stimulating the sciatic nerve percutaneously. The animal's foot is strapped to a plate attached to a pulley system so that plantar flexion of the foot lifts a weight. Ankle flexors contract eccentrically during the concentric contraction of the ankle extensors. A single exercise bout involves 4 sets with 6 repetitions in each set at 80% of the maximum load the rat is able to lift. Each repetition is held for 2.5s, with a 20s rest between reps and a 5 minute rest between sets. Young rats exercised using this paradigm experience a 30% decline in isometric TA muscle force at all frequencies of stimulation 1 and 2 days after exercise. Normalized (to TA dry wt.) twitch and tetanic force are equally affected. The ability of the TA to develop posttetanic potentiation is affected at 1 day, and is significantly reduced at 2 days, suggesting a possible alteration in excitation/contraction coupling after eccentric injury. We are currently assessing the response of older muscles to the exercise paradigm. (Supported by NIA and UCDMC Research Fund).

31.13

A COMPARISON OF THE EFFECTS OF ECCENTRIC AND CONCENTRIC EXERCISE ON PHOSPHATE SPECTRA OF HUMAN SKELETAL MUSCLE
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Unaccustomed exercise induces delayed changes in muscle structure and function that suggest damage to the tissue. These changes, observed primarily after eccentric exercise,appear to be related to work intensity. It has also been reported in studies using phosphorus magnetic resonance spectroscopy (31P-MRS) that such exercise also increases the ratio of inorganic phosphorus to phosphocreatine (Pi/PCr) suggesting that this parameter may be an indirect measure of exercise-induced muscle damage. To date, concentric exercise has not proven to be as an effective stimulus as eccentric for these perturbations. In this study, we examined Pi/PCr in human forearm muscles in the days following a bout of near-maximum concentric exercise or one of four eccentric exercise intensities. Eccentric exercise(E) intensities used were 40, 80, 120, and 140% of maximum concentric strength (MVC), whereas the concentric load was 90% of MVC. Although the two lowest intensity eccentric groups showed no change in Pi/PCr, the value at E120 increased by 75%, E140 by 38%, and C90 by 45%. We conclude that, given sufficient intensity, both concentric and eccentric work can result in increased Pi/PCr. In addition, stepwise increases in eccentric intensity do not result in comparable increases in Pi/PCr suggesting that this parameter may not be the critical determinant in the observed changes in Pi/PCr that accompany exercise.

31.14

THE LONG TERM EFFECTS OF ECCENTRIC EXERCISE ON MOUSE TIBIALIS ANTERIOR MUSCLE.
P. Sacco* & D.A. Jones* (SPON: D.L. Turner)
University College London, London WC1E 6BT, England.

Although the short term effects of eccentric exercise have been well described in both human and animal models, few studies have investigated the long term consequences of damaging exercise on muscle morphology and functional characteristics. We exercised tibialis anterior (TA) muscles of C57/Bl10 mice with eccentric contractions (Sacco et al, *Clin. Sci.*, **82**, 227-236) and measured muscle mass (MM), maximal tetanic force (MF), and mean fibre area (FA) after different recovery periods. Values are means±sem.

	n	MM (mg)	MF (N)	FA (μm^2)
Control	17	44.1(±.13)	0.96(±.04)	3206(±224)
20 day	6	42.4(±.27)	0.83(±.11)*	2972(±593)
42 day	5	46.5(±.34)*	1.05(±.09)*	3447(±678)
84 day	6	48.9(±.30)*	1.11(±.14)*	3580(±625)

By 20 days exercised muscles had not fully recovered, but 42 and 84 days after exercise muscles were significantly larger and stronger (*, $p<0.05$, paired t-test) than non-exercised contralateral TAs and showed large numbers of fibres with central nuclei (indicative of previous necrosis). The results indicate that an episode of muscle damage can lead to a sustained increase in muscle mass and strength in the mouse.

31.15

EFFECTS OF INSULIN ON GLYCOGENOLYSIS, TWITCH TENSION AND ULTRASTRUCTURE OF ISOLATED ELECTRICALLY STIMULATED RAT EPITROCHLEARIS MUSCLE. W.S. Parkhouse and G. Linton. Kinesiology, Simon Fraser University, Burnaby, B.C., and Physical Education, Univ. of Alberta, Edmonton, Alta., CANADA.

The purpose of this study was to examine the responses of rat epitrochlearis muscle to electrical stimulation in the presence and absence of insulin. Epitrochlearis muscles were obtained from male Sprague Dawley rats. Muscles were stimulated in the presence or absence of insulin with 10 volt square pulses of 2 ms duration at a frequency of 2 Hz for 10 minutes or until maximal tension had declined to 20 percent of initial values (63 ± 3 min. with insulin; 47 ± 3 min. without insulin). Control muscles were incubated for similar time periods. Initial rates of glycogenolysis were greatest in the absence of insulin (1.5 vs. 0.6 umol/g/min) whereas subsequent glycogen breakdown was highest in the presence of insulin (0.17 vs. 0.11 umol/g/min). Peak twitch tension declined rapidly in the first ten minutes of stimulation with a greater decline in tension occurring in the absence of insulin (48 vs. 37 percent decrease). Overall, the rate of tension decline was slower in the presence of insulin. A greater proportion of the glycogen was oxidized in the presence of insulin as indicated by the lower lactate accumulations in these muscles. The degree of ultrastructural abnormalities was accentuated in the absence of insulin. In the presence of insulin, the fibers demonstrated swollen and vesiculated mitochondria whereas in the absence of insulin, widespread vacuolation was also observed.

This work was supported by a NSERC grant to WSP.

32.1

LENGTH TENSION RELATIONSHIP AND RELATIVE FIBRE LENGTH VARIABILITY OF RAT SKELETAL MUSCLE AT DIFFERENT AGES. M.A.N. Lodder*, A. de Haan* and A.J. Sargeant. Department of Muscle and Exercise Physiology, Vrije University, Academic Medical Centre, Amsterdam, The Netherlands.

Young rats (40 days) have a ~25% lower specific muscle force compared to older rats (Lodder et al., 1992, J. Muscle Res. Cell. Motil. In Press). One explanation would be if, in the younger rats, there was a greater variability of relative fibre lengths at muscle optimum length (see Jones et al., 1989, Quart. J. Exp. Physiol. 74, 233-256). We tested this hypothesis by measuring the length tension relationship of EDL muscle in 40 and 120 days old rats. Isometric force generated in 150ms tetani was measured at lengths varying from 40 to 170% of the length (L_0) at which maximum active force was generated. No age difference was revealed by the length tension relationships. The muscle was then fixed in glutaradehyde at L_0 in the passive state, macerated and dissected. No significant difference was found in mean (± SD) sarcomere lengths between the young and older animals (2.71 ± 0.27 and 2.76 ± 0.34 µm: mean of >300 fibres at each age).
The distribution of fibre lengths was however different. In the young rats a greater proportion of the fibres were close to the mean. In young *rat 67%* of fibres were within 95 to 105% of L_0, compared to only 46% in older rats ($p<0.001$). Thus the trend was the opposite to that proposed in the initial hypothesis and the difference in specific force observed previously remains unexplained.

32.2

AGE-RELATED CHANGES IN FIBRE TYPE COMPOSITION AND SPECIFIC FORCE OF RAT SKELETAL MUSCLE. C.J. de Ruiter*, A. de Haan*, A. Lind* and A.J. Sargeant. Department of Muscle and Exercise Physiology, Vrije University, Amsterdam, The Netherlands.

During maximal dynamic exercise young rats showed a greater loss of power compared to mature animals (de Haan et al., Pflügers Arch. 412, 665-667,1988). The greater extent of fatigue corresponded with a greater increase in IMP. A change towards a more fatigue-resistent fibre type composition during growth could explain the differences in fatiguability as well as in IMP production, since the enzyme AMP deaminase is more active in faster fatigue-sensitive muscles. Therefore in the present study age-related changes in fibre type composition of rat medial gastrocnemius muscle were measured. Maximal isometric force and fibre length were measured at muscle optimum length (Lo) in 4 different age-groups of male rats.The muscles were weighed and frozen in isopentane at Lo. Specific force (force/ CSA) was not different between the groups of 2, 5 and 22 months old. However, in the youngest group (1.3 months old) specific force was ~30% lower ($p<0.05$). Fibres were classified into 4 different types (I, IIA, IIBd and IIBm; Lind & Kernell, J.Histochem.Cytochem. 39, 589-597, 1991). Both types I and IIA occupied less than 5% of the total cross-section in all 4 age groups. In contrast to specific force, the relative areas of types IIBd and IIBm also changed *after* the age of 2 months ($p<0.05$). The mean relative areas were 23.6, 28.9, 39.8 and 35.5% (type IIBd), and 67.9, 61.2, 52.9 and 54.9% (type IIBm) for the groups of 1.3, 2, 5 and 22 months old, respectively. Thus, the change in specific force during growth was not related to inter-conversion of fibre types. The results further indicate that during growth a shift occurred from a more glycolytic to a more oxidative fibre composition, which may have affected fatiguability and IMP production during exercise.

32.3

AGING AND MUSCLE CONTRACTILE FUNCTION AFTER STRETCH-OVERLOAD. Stephen E. Alway and James A. Carson. Neuromuscular Laboratory, The Ohio State University, Columbus, OH 43210

The *effects of aging on* muscle contractile function after stretch-overload was examined in the anterior latissimus dorsi (ALD) muscle of 10 old (90 weeks) and 10 young adult (10 weeks) Japanese quails. Stretch was achieved by adding 10% of the bird's body weight to one wing while the contralateral wing served as the intra-animal control. This resulted in an increase in muscle mass of 152% in young and 101% in old ALD muscles. In vitro contractile measures were made at 25°C by indirect stimulation of the ALD by its nerve (pulse = 0.1ms). Compared to control twitch characteristics, stretch enlarged muscles had significantly greater contraction time in both old (174 ± 16 ms vs. 217 ± 18 ms) and young (159 ± 9 vs. 177 ± 8) birds. Similarly, one-half relaxation time of the twitch increased after stretch in old (215 ± 14 vs. 252 ± 17 ms) and young (161 ± 7 vs. 187 ± 11) muscles relative to control. Stretch resulted in fusing of twitches at lower frequencies of stimulation, and shifted the force-frequency curve to the left in both age groups. In young adult birds, maximal shortening velocity (V_{max}) decreased from 2.6 ± 0.2 to 1.2 ± 0.1 fiber lengths/s. Although V_{max} was decreased by stretch in old muscles, (1.19 ± 0.02 vs. 0.79 ± 0.06 fiber lengths/s) the magnitude of change was less than in younger muscles. Maximal tetanic force increased by 2.6 fold and 1.7 fold in young and old overloaded muscles, respectively. These data suggest that stretch-overload decreases V_{max} and increases twitch duration in young and old muscles. The attenuation of stretch-induced contractile change in old vs. younger muscle was due in part to an age-induced slowing of this muscle.

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32.4

AGE-RELATED DECLINE IN DIAPHRAGM MUSCLE FORCE. Luc E. Gosselin,* Bruce D. Johnson,* and Gary C. Sieck. Depts. Anesthesiology and Physiology, Mayo Clinic, Rochester, MN 55905

Physical activity has been reported to decrease during the lifespan of both humans and rats. This alteration in activity pattern is known to influence biochemical and morphological properties of skeletal muscle. In contrast to locomotor skeletal muscle activity, the ventilatory pattern remains relatively constant during the lifespan. In this study, we examined the influence of aging (6 mo vs 24 mo) on the in vitro isometric contractile and fatigue properties of the Fischer 344 rat diaphragm (DIA). The senescent rats demonstrated a small but significant ($P < 0.05$) shift in the pressure-volume relationship of the lung (108% at total lung capacity). Time to peak twitch force and 1/2 relaxation time did not differ between groups. However, there was a significant decrease (15-18%, $P < 0.05$) in the specific force (N/cm^2) of the senescent DIA at all stimulation frequencies (10-100 Hz). DIA fatigue, induced by 40 Hz, 330 msec duration, 1/sec for 2 min, did not *significantly* differ between the two groups. These results indicate that although aging has no effect on DIA muscle fatigue properties, the maximal isometric force of the DIA is significantly reduced in senescent rats. These observations may in part be due to previously observed changes in myosin heavy chain composition of the senescent DIA. Supported by NIH grants HL 34817, HL 37680 and GM 08288.

32.5

CHRONIC STIMULATION OF SENESCENT SKELETAL MUSCLE INDUCES PARALLEL INCREASES IN ß RECEPTOR DENSITY AND AEROBIC CAPACITY. R.P.Farrar , T.J.Walters, K. Monnin*, and R.E. Wilcox*. Dept. of Kinesiology, Univ. of Texas, Austin, TX, 78712

Previously we (Monnin et al, 1990) confirmed reports of Williams et al (1984) that endurance training in young rats induced concomitant increases in ß receptor density and aerobic capacity of skeletal muscle. This *relationship* between increases in aerobic capacity and ß receptor density was not maintained in skeletal muscle during the aging process when the rats were subjected to an endurance training regime. The aerobic capacity of the senescent skeletal muscle increased, but there was no change in ß receptor density or Km. In the current study we examined the effect of chronic 10 Hz. stimulation of the tibial nerve upon aerobic capacity and ß receptor density of the plantaris muscle in young(10-12 mo.) and senescent (25-27 mo) F344 male rats. In the young rats the Bmax increased from 9.2± 1.1 to 19.1±1.6 fm/mg while the citrate synthase activity increased from 32.6 ± 1.2 to 61.9± 6.6 µmol/g. The senescent rats increased the ß receptor density from 9.1 ±1.0 to 18.5 ± 1.9 while the citrate synthase activity increased from 26.7±1.3 to 55.4± 6.4 µmol/g. These data provide evidence that (1) declines in oxidative capacity during the aging process are not mirrored by declines in ß receptor density; and (2) although endurance running is insufficient to induce increases in ß receptor density, chronic 10 Hz stimulation will maximally activate the contraction-dependent pathway and induce increases in both ß receptor density and aerobic capacity in senescent skeletal muscle.

32.6

METABOLIC RESPONSES DURING VOLUNTARILY AND ELECTRICALLY INDUCED DYNAMIC REPETITIONS IN MAN. C. K. Kim, J. Bangsbo*, J. karpakka**, and B. Saltin
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August Krogh Institute, Denmark*. Deaconess Institute of Oulu, Finland

Muscle inactivity deteriorates its function and becomes hypotrophic with prolonged disease as after an injury or a stay in space. In both situations electrical stimulation(EMS) of the muscles have been proposed to be used to limit effect of the inactivity. To achieve this propose static contraction has been well studied, but little known about dynamic contractions. This study was performed and evaluate the metabolic response to voluntarily as well as electrically induced contractions. Subject performed leg extensor exercise during an incremental(0W-40W) and a prolonged exercise(60 min). In incremental exercise blood flow and metabolic fluxes were measured from femoral arterial- venous blood samples at given work load. In prolonged exercise muscle biopsies were obtained from vastus lateralis(VAS) and rectus femoris(REC) at rest and immediately after exercise. Intramuscular pressure(IMP) were measure in VAS and in deep as well as superficial regions. In the incremental exercise leg blood flow increased with work intensity reaching 7.2 l/min in both exercise modes at 40W, but only significantly difference($p<0.05$) at 10W. Mean blood lactate and ammonia efflux were several fold higher during EMS. The exaggerated metabolic response with EMS was also true for the prolonged exercise. Duing EMS glycogen content in VAS rated as 22%, 25%, and 28% of PAS negative in type I, type IIa and typeIIb fibers, respectively, whereas during VOL only 0.8% of PAS negative in type I and type II fibers. Glycogen depletion in REC occured more drastically in all fiber types, but preferentially depleted in type II fibers with EMS. The recruitment pattern of different muscle groups was simular in VAS and REC. In conclusion, electrically induced stimulation of muscle might be an efficient count measure to devoid disease atrophy. The study was supported by NASA grant NAG 9 -363.

32.7

SKELETAL MUSCLE ADAPTATION: ISOKINETIC VERSUS ELECTRICAL STIMULATION SUPERIMPOSED ON ISOKINETIC EXERCISE. G.G. Sleivert, G.J. Bell, R.S. Burnham, and T.P. Martin. Univ. of Alberta, Edmonton, AB. Canada, T6G 2E1

The purpose of this study was to determine whether voluntary strength training (VST) and percutaneous electrical stimulation superimposed on voluntary strength training (EVST) elicited differential adaptation of muscular strength and endurance and metabolic markers of myofibrillar adenosinetriphosphatase (ATPase), α-glycerolphosphate dehydrogenase (GPD) and succinate dehydrogenase (SDH) activity as determined by quantitative histochemical techniques. Eleven males and females, 21.2,0.3 years of age, weighing 66.7,10.7 kg (mean,SD), trained the knee extensors on one leg using VST and on the contralateral leg using EVST 4x per week for 6 weeks on a Cybex isokinetic dynamometer (1.05 rads·s^{-1}). Similar gains in peak torque (9.0,9.1%) and endurance, as indicated by time until a 50% drop in peak torque occurred (34.1,41.7%) were observed for VST and EVST, respectively. ATPase and GPD activity did not change for either training condition however SDH activity increased by 28.3% for VST (NS) and 47.9% for EVST ($p<0.05$). These data suggest that EVST has no greater effect on enhancing strength than VST alone. A trend towards greater muscular endurance and the higher SDH activity after EVST versus VST suggests a greater effect of EVST on the fatigue resistance of skeletal muscle.

32.8

THE EFFECT OF HIGH-INTENSITY EXERCISE TRAINING ON RAT SINGLE MUSCLE FIBER FORCE, Vmax, AND THE FORCE-VELOCITY RELATIONSHIP. C.J. Vergoth* and R.H. Fitts. Marquette University, Milwaukee, WI 53233.

The purpose of this study was to determine the effects of sprint training on the contractile properties of the three fiber types in the rat. Exercise trained rats ran 6 bouts (4.5 min) at 40 m/min up a 15% incline with 2.5 min rests, 5 days/wk for 6 wks. Single skinned fibers were isolated from the soleus (SOL) and the deep red (RG) and superficial white (WG) region of the gastrocnemius, suspended between a motor arm and force transducer, and fiber diameter, peak force (Po, kN/m^2), the maximal shortening velocity (Vmax), and the force-velocity relationship determined. Fiber diameter (μm) was unchanged by the exercise except for a significant decrease in the RG type I fiber. The exercise significantly reduced Po in the slow type I and fast type IIa fibers. Vmax of the trained SOL type I and the RG type IIa fibers was significantly higher while the WG type IIb Vmax decreased. Despite the significant changes in Vmax, none of the fibers showed an altered MHC profile. Sprint training resulted in an increased velocity at loads less than 10% in the SOL type I fibers, and a decreased velocity at loads less than 15% in the WG type IIb fibers. The peak power output was significantly decreased in the trained SOL and RG type I fibers, but unchanged in the trained fast IIa and IIb fibers. In conclusion, high-intensity exercise significantly decreased Po and increased Vmax in the SOL type I and RG type IIa fibers.
Supported by NIH AR39894.

32.9

EFFECT OF PROLONGED ENDURANCE EXERCISE ON DIAMETER AND PEAK FORCE IN SLOW AND FAST FIBERS OF THE RAT. L.V. Thompson, C.J. Vergoth*, and R.H. Fitts. Marquette University, Milwaukee, WI 53233.

The purpose of this investigation was to evaluate the effects of prolonged endurance exercise training (ET) on slow and fast fiber function in rats. The rats ran 5 days a week, 3.5 hrs per day at 27 m/min up a 15% grade, for 8-12 wks. Single skinned fibers were isolated from the soleus (SOL) and deep red (RG) and superficial white (WG) region of the gastrocnemius, suspended between a motor arm and force transducer, and fiber diameter (μm) and peak force (P_o, kN/m^2) determined. The diameters of the slow- and fast-twitch fibers were unaffected by training. P_o of the WG fast fibers was not altered, whereas P_o of the RG fast fibers and SOL and RG slow fibers was significantly reduced by training (Table 1). Collectively, these data suggest that prolonged ET produces no change in fiber diameter and a significant decrease in P_o.

	Fiber Diameter (μm)		Peak Force (kN/m^2)	
	C	ET	C	ET
Soleus type I	75±4	82±2	101±5	77±3*
RG type I	74±2	78±3	104±5	82±4*
RG type II	65±2	72±3	121±4	96±4*
WG type II	67±3	70±2	89±3	93±5

Supported by NIH AR39894.

32.10

FORCE/VELOCITY RELATIONSHIP IN ELITE AND COMPETITIVE ROAD AND TRACK CYCLISTS

G.M.Bogdanffy, S.L.Griffith, and D.D. Ohnmeiss*. Texas Back Institute Research Foundation, Plano, Tx. 75075

Previous studies regarding force-velocity (F-V) curves have demonstrated strong inverse relationships, both in vivo and vitro. In addition, F-V curves are influenced by individual percentage of fast and slow motor units, favoring the former. The purpose of this investigation was to compare the difference in F-V curves in elite/competitive road and track cyclists, utilizing isokinetic dynamometry. Ten United States Cycling Federation (USCF) *licensed category* 1,2, and 3, (4 track, 6 road) cyclists were tested isometrically, and isokinetically at 60°, 90°, 120°, 180°, and 240°/sec., for both knee extensors through a 90 ROM. The testing protocol consisted of a ramping series, with 25%, 50%, 75%, effort followed by 5 maximal voluntary concentric knee extensions. Peak torques were recorded at all velocities. The following data represents the average peak torque at each velocity normalized to each cyclists peak isometric torque.

Velocity	60°	90°	120°	180°	240°
Track	0.82	0.76	0.72	0.57	0.49
Road	0.86	0.73	0.69	0.60	0.48

No significant differences were detected between groups at any velocity, in addition, there was no difference in isometric values, although there was a trend. 233 ± 32 vs 211 ± 30ft/lbs These data demonstrate F-V curves similar to those previously reported, and that although these athletes train and race in different events, these differences cannot be explained through isokinetic spectrum analysis.

32.11

DYNAMIC FEATURES OF THE HUMAN QUADRICEPS AT DIFFERENT LEVELS OF NEURAL ACTIVATION. F. Saibene*, M. Bordini* and M.V. Narici. CNR, Istituto Tecnologie Biomediche Avanzate, Fisiologia, Milan, Italy 20131

It is well established that a direct proportionality exists between the integrated electrical activity of a muscle (iEMG) and the isometric force. A 'family' of force/velocity (F/V) curves may thus be obtained according to different levels of neural activation. In this study the F/V features of the human vastus lateralis (VL) and vastus medialis (VM) muscles were compared when shortening occured under conditions of maximal and submaximal neural activation. In six male subjects (age 35.3±3.6 yr, weight 70.8±7.0 kg) iEMG of VL and VM were measured while ergometer cycling against friction loads of 0, 1, 2 and 3 kg, at rates of 30, 60, 90, 120 revolutions per minute (rpm) and as fast as possible (Vmax). Two of these subjects also pedalled against 4 kg. For each pedalling velocity, the iEMG of VL and VM increased linearly as a function of the load (F) and could be represented by $iEMG = \alpha + \delta \cdot F$ where α = constant at zero load and δ = increase in EMG per unit increase in load. All functions had very similar common origins corresponding to the internal load of the system. The iEMG activity remained constant when the subjects pedalled at the Vmax attainable for each load. It was thus assumed that this level represented maximum neural activation (iEMGmax) and all iEMG values were normalised as percent of this maximum. By imposing an activation level of 50% iEMGmax, the corresponding F for each velocity was calculated using the equation $iEMG = \alpha + \delta \cdot F$. From the F and V coordinates a F/V curve was constructed and by plotting (Vo-V)/F against V the constants a and b of Hill's equation were calculated from the slope (1/a) and intercept (b/a) of the curve. For both VL and VM the F/V curves obtained at 50% iEMGmax had Vmax values which corresponded to those obtained at 100% iEMG (Vmax = 198.8 rpm) the corresponding curve calculated at 100% iEMG closely fitted the experimental data obtained during maximum cycling against friction loads of 1, 2, 3 and 4 kg. It may be thus concluded that the force/velocity features of the human quadriceps under conditions of submaximal activation are comparable to those observed when activation is at a maximum.

32.12

THE EFFECT OF GLYBURIDE, A $K^+_{(ATP)}$ CHANNEL ANTAGONIST, ON FORCE DEVELOPMENT AND ACTION POTENTIAL IN THE FROG SARTORIUS MUSCLE. P. Light*, A. Comtois and J.M. Renaud. Dept. of Physiology, University of Ottawa, Ontario, Canada.

The function of $K^+_{(ATP)}$ channels in skeletal muscle is still unclear, though a possible role in the mechanism of fatigue has been implicated. That is, an activation of the $K^+_{(ATP)}$ channels gives rise to greater K^+ efflux and faster decreases in force during fatigue. In this study we tested whether $K^+_{(ATP)}$ channels become active during fatigue development by exposing frog sartorius muscles to 100 μmole·l^{-1} glyburide. Our results show that 1) glyburide had no effect on tetanic force or action potential before fatigue; 2) following fatigue (1 tetanic contraction/sec for 3 min) the width of the action potential was larger in the presence than in the absence of Glyburide; but 3) the inhibition of the $K^+_{(ATP)}$ channels by Glyburide resulted not in slower but faster decreases of tetanic force during fatigue development when compared to control muscles. Thus, there is evidence for an activation of $K^+_{(ATP)}$ channels during fatigue development, but further studies are necessary to understand their role. (Supported by NSERC of Canada).

32.13

SKELETAL MUSCLE ELECTRICAL ACTIVITY DURING +Gz ACCELERATION. Ira Jacobs and Bruce Bain*. Defence & Civil Institute of Environmental Medicine, North York, Ontario, M3M 3B9

A strategy used by combat pilots to increase their tolerance of headward acceleration (+Gz) forces is to repeatedly do a Valsalva maneuver while contracting large skeletal muscle groups in order to raise systemic blood pressure. This investigation used surface electromyography (EMG) to estimate the intensity of contraction by several muscles in 8 male subjects during +Gz exposure in a human centrifuge. All subjects were experienced and underwent similar training in enhancing +Gz tolerance via muscle contraction. Before the centrifuge ride, the EMG activity of 7 muscles was recorded during a maximal voluntary isometric contraction (MVC). The EMG of these same muscles was then simultaneously recorded during the +Gz ride, which was alternating 15-s bouts at each of +4 and +7Gz until voluntary exhaustion. +Gz tolerance time (GT) averaged 256±(SD) 93 s. The root mean square of the EMG activity during each 7G bout was averaged for each subject and expressed relative to the 100% MVC values. The mean values (±SD) were: biceps brachii, 26±18%; latissimus dorsi, 44±38%; pectoralis major, 49±35%; rectus abdominis, 31±28%; vastus lateralis, 43±21%; biceps femoris, 31±26%; gastrocnemius, 39±41%. There was no statistically significant difference between muscles. GT was most significantly correlated with the biceps femoris EMG (r=-0.84). Assuming the EMG reflects the extent of motor unit activation, then particularly noteworthy is the fact that less than 50% of the maximal electrical activity was recorded from all muscles.

32.14

EVIDENCE FOR AN ADDITIONAL MECHANISM OF ACTION OF INORGANIC PHOSPHATE (P_i) ON FORCE GENERATION OF SKELETAL MUSCLE. Mark A. Andrews. NY Coll. Osteopath. Med., Old Westbury, NY.

The effects of P_i on maximal force generation (F_{max}) of muscle are well established, with a reversal of the force producing steps of the crossbridge cycle being the putative mode of action. Presently, in light of the effects of altered ionic environment on muscle proteins (Andrews et al. 1991. J. Gen. Physiol. 98:1105), an additional mechanism is proposed: that binding of P_i to myofilaments leads to their destabilization and decreased F_{max}. To illustrate, F_{max} was monitored as single chemically-skinned (Triton X-100) fibers of fast-twitch rabbit psoas were randomly activated (pCa 4) in solutions containing (mM): 5 EGTA, 20 Imidazole, 2 Mg^{2+}, 5 MgATP, 15 PCr, at pH 7. To this, all combinations of 0, 5, 10, 15 and 30 mM P_i (K_2HPO_4), and 0, 100 and 300 mM of the protein stabilizer trimethylamine N-oxide (TMAO; Fogaça et al. 1990. Biophys. J. 57:546) were added. Total ionic strength was brought to 200 mM with $KMeSO_3$. Results show that while P_i decreased F_{max} dose-dependently, 100 and 300 mM TMAO completely reversed the effect of 5mM P_i, while ameliorating the effects of higher P_i levels. Therefore, in addition to other effects, P_i is proposed to inhibit F_{max} by binding to and destabilizing muscle proteins, a condition not favored in the presence of TMAO. Furthermore, in the presence of 30 mM P_i, the fibers swell, possibly due to binding of P_i and increased repulsion within the myofilament lattice. TMAO counteracts this effect.

32.15

ELECTROPHYSIOLOGICAL ACTIVATION PATTERNS VERSUS TENSION GENERATION IN STIMULATED LATISSIMUS DORSI MUSCLE. J.A. Dunn and R.L. Kao. ETSU, JH Quillen COM, Johnson City, TN 37604

Many advances have been made in biomechanical cardiac assist technology derived from conditioned, fatigue resistant skeletal muscles. Tetanic stimulation with resultant summation of individual twitches results in greater force generation. However, the mechanism of increased contractile force evoked by nerve vs. intramuscular stimulation (IMS) remains unclear. Electrophysiological mapping (EPM) and tension generation were analyzed to delineate whether higher tension generation is the result of increased temporal summation, increased recruitment, or both. A 56-lead EPM array and isometric force transducer were attached to 7 canine latissimus dorsi muscles (LDM) in situ. Supramaximal stimulations were given through paraneural, proximal, middle and distal intramuscular electrodes. Stimulation through paraneural or proximal IMS resulted in homogeneous, orthodromic activation. Middle and distal IMS resulted in heterogeneous activation with multiple sites of initial activation and non-depolarization. Contraction profiles revealed greater peak tension x time product for paraneural and proximal IMS vs. middle and distal IMS. Analysis reveals paraneural and proximal IMS was associated with a greater number of active electrodes, but no significant difference in mean activation time and degree of activation temporal dispersion. We conclude that the greater tension generation observed following paraneural or proximal IMS was a result of a greater total number of myofibers, not temporal summation. (Supported by NIH Grant HL38078)

ENERGETICS

33.1

CONTROL OF OXIDATIVE METABOLISM BY CYTOSOLIC PHOSPHORYLATION POTENTIAL IN SLOW TWITCH MUSCLE, *IN SITU*. Susan J. Harkema and Ronald A. Meyer. Michigan State University, E. Lansing MI, 48824.

Phosphcreatine (PCr), oxygen consumption (VO_2), and *maximal twitch* force measurements were obtained from cat soleus muscle, *in situ*, at rest and during submaximal stimulation rates. PCr concentration was measured by phosphorous *nuclear magnetic resonance* spectroscopy. The monoexponential time constant for PCr changes was independent of stimulation rate and similar between onset of stimulation and recovery (τ = 0.83 $\pm$ 0.07 min). Steady-state PCr level and VO_2 were linearly related to the product of stimulation rate times peak twitch force. Our results indicate a linear relationship between steady-state PCr levels and VO_2 throughout submaximal ATPase rates, contrary to results in isolated perfused cat soleus muscles. These results support linear models of oxidative metabolism in skeletal muscle, with respiration rate dependent on the difference between the cytoplasmic and the intramitochondrial free energy of ATP hydrolysis. (Supported by NIH AR38972)

33.2

31P-MRS power output/oxidative energy coupling at the onset of work in human muscle. T. Binzoni, E. Hiltbrand, G. Ferretti and P. Cerretelli. Departments of Physiology and Radiology - University of Geneva Medical School, Geneva - Switzerland

The $\dot{M}O_2$ kinetics in human muscle upon imposing constant work loads can be estimated from the analysis of gas exchange transients in the lungs. However, the accuracy of this method in man is limited by physiological variables such as the circulation delay from the contracting muscle to the lung, changes of the O_2 stores and transient anaerobic glycolysis. The kinetics of $\dot{M}O_2$ in human *calf muscle* (soleus and gastrocnemius) was recently determined from the time course of PCr hydrolysis (31P-MRS). The obtained function may be approximated to a monoexponential with a t, for sedentary subjects, of ~23 s. In the aerobic domain, t is independent of the power output ($\dot{w}$) and is an index of the $\dot{w}$-$\dot{M}O_2$ coupling of the investigated muscle mass (1). Changes of t can be estimated in a much simpler way (*provided magnetization transfer effects* (2) are not influenced by changes of enzymatic activities) than the measurement of the kinetics of PC hydrolysis, from the slope of the linear relationship between [PCr] at steady state and $\dot{w}$. A perfectly tight power output/oxidative energy coupling will result in a horizontal [PCr] vs $\dot{w}$ relationship. Muscle metabolic adaptive changes (e.g. induced by training, acclimatization to hypoxia, etc.) or pathological conditions can be easily investigated by this approach. The t values obtained for given muscles can be compared to homologous t values of $\dot{M}O_2$ measuremens.

(1) Binzoni T. et al., Phosphocreatine hydrolysis by 31P-NMR at the onset of constant-load exercise in man, J. Appl. Physiol. (in press).

(2) Binzoni T. and Cerretelli P., Muscle 31P-NMR in humans: estimate of bias and qualitative assessment of ATPase activity, J. Appl. Physiol., 71(5): 1700-1704, 1991.

33.3

GATED 31P-NMR CONFIRMS DECREASED ENERGY COST OF ISOMETRIC TWITCHES IN ATP-DEPLETED RAT MUSCLE

Jeanne M. Foley , Anthony T. Paganini, and Ronald A. Meyer . Michigan State University, E. Lansing, MI 48824

Depletion of ATP has been shown to reduce the initial rate of phosphocreatine (PCr) hydrolysis as estimated from the time zero derivative of an exponential fit of 30 s block average 31P-NMR data obtained during 8 min of 0.75 Hz isometric contractions in rat skeletal muscle. The same in situ model of rat gastrocnemius depleted of ATP with the purine nucleotide inhibitor, hadacidin, was examined in this study using 31P-NMR acquisitions gated to precise time points (1, 16, 36, 56, 176, and 236 s) following a burst of 10 twitches at 2 Hz. Spectra for each time point were derived by summing data from 8 successive cycles. Immediately after the contraction burst, PCr levels were reduced 9.6 ± 1.0 % (SE, n=5) in controls vs. 4.9 ± 1.2% in muscles with 40% less ATP than controls but normal initial PCr content. Normalizing for the slightly lower twitch force in the depleted muscles (1.08 ± 0.06 vs. 1.27 ± 0.08 g/g body weight), this represents a 40% decrease in energy cost of contraction in the depleted muscles, in agreement with the earlier report.

(This work was supported by NIH Grant # AR-38972)

33.4

OXIDATIVE CAPACITY OF THE MEDIAL AND LATERAL GASTROCNEMIUS USING A SIMPLE ^{31}P-NMR LOCALIZATION PROCEDURE.

Kenny De Meirleir, Krista Vandenborne*, Kevin McCully and John S. Leigh*, MMRRCC, Dep. of Radiology, University of Pennsylvania, Philadelphia, PA 19104. Dep. of Sports Medicine, Free University Brussels, Belgium.

Our goal was to compare oxidative capacity of the medial and lateral gastrocnemius, using a simple localization procedure. In order to localize the ^{31}P signal to the medial or lateral gastrocnemius, a 2 segment meander coil (6 x 10 cm) was built. ^{31}P spectra of a phantom imitating the leg structure showed that 85% of the signal was obtained from one section of the gastrocnemius. Exercise consisted of repeated plantar flexions, one every 4 seconds, performed for 5 minutes. The workload was increased every minute to deplete PCr to 50-60% of the initial value by the end of exercise. No drop in pH was seen during exercise.

As exercise was stopped PCr recovered and returned to the initial resting values. The PCr areas during recovery were fit to a single exponential curve with time constants of 33.6 ± 7.5 s for the lateral gastrocnemius and 35.3 ± 7.0 s for the medial. Assuming a rest value of 28 mM PCr at rest and creatinekinase at equilibrium we calculated a Vmax of 52.1 ± 13.3 mM ATP/min in the lateral and 49.4 ± 12.3 mM ATP/min in the medial gastrocnemius.

In conclusion ^{31}P spectra could be localized to the medial or lateral gastrocnemius, using a 2 segment meander coil. Although the *medial* gastrocnemius was more active at low work levels than the lateral gastrocnemius, the metabolic capacities in both muscles were similar.

K.V. is supported by the N.F.W.O..

33.5

Myocardial metabolism during aerobic exercise by ^{31}P NMR in human

Shin-ya Kuno, Yuji Itai and Shigeru Katsuta Department of Sports Sciences, University of Tokyo, Institute of Clinical Medicine and Health and Sport Sciences, University of Tsukuba, Japan

A few studies has been made *in vivo* on human myocardial energy metabolism at rest. However, no discussion has been made on metabolism during exercise and training effects. We examined human myocardial energy metabolism at rest and during exercise and training effects on the metabolism by ^{31}P NMR. Three sedentary male students (Cont) and 4 male long distance runners (Tr) were employed. The NMR spectra were obtained from myocardium during rest and exercise by region selection method. As a method of exercise load during ^{31}P NMR measurement, a rotation movement of legs while riding a bike fitted with an ergometer we made ourselves for NMR was used at a certain load. The heart rate was in a stationary phase during exercise. Although the heart rate at rest in Tr group was significantly lower (Tr: 53.3±3.2 bpm, Cont: 65.3±2.2 bpm), no significant difference was observed in myocardial energy metabolism by ^{31}P NMR (Tr: PCr/ATP 1.51±0.03, Cont: 1.51±0.01). When NMR measurements were investigated at a two different intensity of exercise, heart rate in Cont group were significantly higher by about 20 bpm than those in Tr group at both exercise intensity, while no difference in energy metabolism was observed between both groups or between rest and exercise (Tr: 76.3±4.3, 88.5±3.5 bpm, PCr/ATP 1.51±0.03, 1.51±0.03, Cont: 95.1±2.1, 115.3±3.9 bpm, PCr/ATP 1.51±0.03, 1.50 ±0.03). Thus, during submaximal exercise, high energy phosphate level normally observed at rest may still be maintained. From these results, the absence of change in the myocardial PCr to ATP ratio suggested that ADP is not the primary regulator of the increased metabolism needed to meet higher cardiac workload during aerobic exercise in both group.

33.6

PHOSPHORUS METABOLISM DURING STEP FUNCTION EXERCISE IN LONG DISTANCE RUNNERS AND SPRINTERS.

Takayoshi Yoshida and Hiroshi Watari Osaka Univ., Osaka and National Inst. Physiol. Sci., Japan

^{31}P nuclear magnetic resonance spectroscopy (^{31}P-MRS) was used for non-invasive measurement of phosphorus metabolisms (creatine phosphate (PCr) and inorganic phosphate (Pi)) and changes in intramuscular pH during a step function exercise and recover. While prone position in a 2.1 T superconducting magnet with a 67 cm bore, six healthy male students, 5 long distance runners and 5 sprinters performed 4 min of femoral flexion exercise at 30 kgm/min, followed by 4 min of recovery. The ^{31}P-MRS was collected with 32 scans per spectrum, requiring 12.8 s. The areas of PCr and Pi peaks were integrated and the time courses of PCr and Pi were fitted to an exponential model. During exercise PCr increased to depletion by 20 - 30 % of the pre-exercise level. Following exercise, the rates of PCr and Pi recovery were significantly faster in long distance runners than in normal subjects ($P<0.05$). During a given intensity of exercise, long distance runners showed less acidification than in normal subjects. Since it is well documented that PCr resynthesis is regulated by aerobic metabolism and mitochondrial creatine kinase, it is suggested that the faster PCr and Pi recovery rates and less acidification seen in long distance runners might result from attributable to the greater oxidative capacity.

33.7

MYOCARDIAL BIOCHEMICAL ADAPTATIONS IN ADULT RATS FED B-GUANIDINOPROPIONIC ACID, A CREATINE ANALOGUE.

G.S. Morris Q. Zhou*, R. Li*, D. Marsh, and T.P.Martin*. Louisiana State Univ., Baton Rouge, LA. 70803, Univ. of Alberta, Edmonton, Canada.

The intent of this study was to determine if a chronic deficit in the energy intermediate phosphocreatine (PCr) altered cardiac energy synthesis or consumption. We pair fed adult, Sprague-Dawley rats either a standard diet (CONT; N=8) or a diet containing B-guanidinopropionic acid (B-GPA; 2% of food intake; EXP; N=8), a compound that reduces cardiac PCr levels. After 8 wks, we analyzed hearts for hexokinase (HK), citrate synthase (CS), 3-hydroxyacyl CoA dehydrogenase (HOAD), calcium activated myofibrillar ATPase (ATPase) activity and myosin isoform distribution.

	HK*	CS*	HOAD*	ATPase*	%V1
CONTR	2.04	656	344	871	>85
EXP	1.88	660	351	908	>85

*(umol/g per min) *(nmol/min per mg protein)

These data further support the argument that, under normal functional demand, B-GPA feeding does not alter cardiac metabolic enzyme activity or contractile energy costs in the adult heart.

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33.8

MUSCLE FATIGUE AND ATP DEGRADATION IN RAT SKELETAL MUSCLE.

A. de Haan*, J.C.M. Koudijs* and H.G. Westra* (SPON: A.J. Sargeant). Department of Muscle and Exercise Physiology, Vrije University, Academic Medical Centre, Amsterdam, The Netherlands.

During high-intensity exercise in man and animals, skeletal muscles loose adenine nucleotides by deamination of AMP to IMP. At exhaustion human muscle biopsies showed 30-40% decreases in ATP. In rat fast muscles even larger decreases are found (de Haan, Exp.Physiol.75, 851-854, 1990). In previous experiments using rat muscles, the loss of force at the end of a series of isometric or dynamic contractions was greater when more muscle adenine nucleotides were degraded to IMP. In the present experiments the relationship between the loss of force and the degradation of ATP was investigated. Medial gastrocnemius muscles (n=30) of anaesthetized rats (pentobarbitone 60mg/kg, i.p.) were stimulated (120Hz) at a temperature of 36°C. The muscle performed a series of contractions during 6s with arrested blood flow. Five different exercise protocols were used, during which the muscles were activated for ~3.4s, to induce differences in force loss (range 8-82% of the force in the first contraction). The reduction of ATP varied between 0 and 18.2 µmoles/g dw (resting ATP concentra-tion was 32.2±1.5 µmoles/g dw). The relationship between the reduction of ATP and the final force (force in the last contraction as a percentage of the initial force) was hyperbolic (Force(final)= 88.9 + 1.14 x (ΔATP) - 0.25 x $(\Delta ATP)^2$; r=0.95). A zero final force was reached with an ATP reduction of 21.5 µmoles/g dw. In previous experiments, it was shown that the loss of ATP was similar to the production of IMP. From the results of these and previous experiments, it seemes more likely that it is the production of IMP rather than the loss of ATP, which may regulate the contractile activity and hence fatigue.

33.9

BIOENERGETIC AND ACID-BASE ADAPTATION TO REPETITIVE SCIATIC NERVE STIMULATION IN RAT LEG MUSCLE BY 31P MRS. R.K. Laderberg*, J. Rose*, and D.M. Systrom. Pulmonary and Critical Care Unit, Mass. General Hospital and NMR Laboratory for Physiological Chemistry, Brigham & Woman's Hospital, Harvard Medical School, Boston, MA 02114

To elucidate mechanisms of fatigue during exercise we used 31P MRS in spontaneously breathing Sprague-Dawley rats lightly anesthetized with ketamine and midazolam. Silver electrodes were attached to the sciatic nerve and supramaximal nerve stimulation (150V) was delivered during an eight minute protocol. Spectra were obtained using an 8.45T magnet interfaced to a Nicolet 360 spectrometer. With a surface coil tuned to 145.75 MHz, pulse=20μs, and TR=3s, 12-16 FIDs were averaged per spectrum. Arterial blood pressure, pCO2 and core temperature remained near normal. Group A rats were stimulated continuously at 5 Hz while the group B protocol utilized varying patterns of high frequency bursts (50-100 Hz X 200-400ms, duty cycle 400ms/s-200ms/5s).

Group	pH rest	pH 2 min	pH 4 min	pH 6 min	pH 8 min
A (n=5)	7.31 ± 0.06	6.90 ± 0.04*	6.52 ± 0.06*	6.79 ± 0.11*	7.04 ± 0.03*†
B (n=7)	7.29 ± 0.04	7.00 ± 0.05*	6.82 ± 0.07*	6.96 ± 0.05*	7.08 ± 0.05*†
Group	PC/Pi 2 min	PC/Pi 4 min	PC/Pi 6 min	PC/Pi 8 min	
A (n=5)	0.45 ± 0.05	0.29 ± 0.03	0.58 ± 0.07	0.76 ± 0.14	
B (n=3)	1.99 ± 0.91	0.90 ± 0.30	1.11 ± 0.37	1.59 ± 0.46	

* $p < 0.05$ by ANOVA, rest vs exercise † $p < 0.05$ by ANOVA, 8 vs 4 min

Within each group the intramuscular pH fell significantly from baseline and then rose significantly above the 4 min nadir despite continuing the stimulation protocol. There were no significant differences in pH between groups at all times. The data suggest adaptive mechanisms attenuate muscle cell contraction to prevent potentially damaging intracellular acidosis or depletion of high energy phosphates.

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33.10

LOCAL MEASUREMENT OF NADH IN SKELETAL MUSCLE DURING REGULATORY ADJUSTMENTS OF BLOOD FLOW. Paul C. Johnson, Miklos Pal*, Andras Toth*,, Marc E. Tischler and Peipei Ping* Univ. of Arizona, Tucson, AZ, 85724.

Shifts from oxidative to glycolytic metabolism have been suggested to be involved in regulation of blood flow in striated muscle. To test this hypothesis we measured NADH fluorescence at localized avascular tissue sites (15-30 microns diameter) in sartorius muscle of the anesthetized cat during ischemia, sympathetic nerve stimulation, arterial pressure reduction and motor nerve stimulation. Flow in nearby capillaries was measured simultaneously except during muscle contraction. Ischemia increased fluorescence by 60 to 80% beginning 45 to 60s after flow stopped and reaching completion in about 3 minutes. In separate experiments we verified that the change in total tissue NADH paralleled the change in fluorescence under different circumstances. Sympathetic nerve stimulation to the muscle at 2-4 Hz reduced flow 20-40% but did not increase fluorescence. At higher frequencies (6-12 Hz) flow fell at least transiently by 80-100% and fluorescence rose by 33±7% of the ischemic change. Fluorescence returned to control during vascular escape. Reduction of blood flow by at least 50% for at least 30 seconds was required to increase NADH fluorescence. When arterial pressure to the muscle was reduced to 80, 60 and 40 mmHg fluorescence often did not change either in the presence or absence of flow autoregulation. Muscle contraction at frequencies up to 20Hz failed to increase NADH fluorescence, although blood flow rose. There is no indication that flow regulation in this muscle is linked to a shift in tissue redox state, as assessed by NADH. (Supported by NIH grant HL17421)

33.11

FATIGUE AFFECTS COUPLING OF CREATINE KINASE TO SARCOPLASMIC RETICULUM CALCIUM-ATPase. Paavo Korge* and Kenneth B. Campbell, Wash St Univ, Pullman WA 99164

Previous experiments have demonstrated that creatine kinase (CK) bound to sarcoplasmic reticulum (SR) membranes is functionally coupled to Ca^{2+} transporting protein, Ca-ATPase; ADP produced by Ca-ATPase is preferentially available to CK for phosphorylation and ATP generated in this reaction is preferentially used for Ca uptake. We hypothesized that coupling of CK to Ca-ATPase is subject to modification with fatigue. To test this hypothesis, experiments were performed on blood perfused rat plantaris m. using a protocol of repeated intermittent tetanic stimulation until developed tension had declined to 30% of its initial level. SR vesicles were isolated from rested and fatigued muscles and vesicular Ca-uptake was measured using two sources of high-energy phosphate: a) ATP and b) CP plus ADP. Under rest conditions, CP-ADP-stimulated Ca-uptake rate was 65% of ATP-stimulated Ca-uptake rate. Under fatigued conditions, ATP stimulated Ca-uptake rate was 84% of that under rest conditions while CP-ADP stimulated Ca-uptake rate was only 68% of that at rest. We conclude that fatigue causes a greater decrease in the function of CK in the local regeneration of ATP near ATP binding sites of Ca-ATPase than the decrease in the function of Ca-pump itself. Possible factors modifying CK coupling to Ca-ATPase during intense exercise are: decreases in [CP]; changes in the amount of membrane bound CK; and modification of SH groups of CK.

33.12

THE ROLE OF CREATINE KINASE IN SINGLE MUSCLE FIBERS OF DIFFERENT TYPES IN RATS. K. Yamashita* and T. Yoshioka* (SPON: A. V. Somlyo**). *Dept. Physiol., St. Marianna Univ. Sch. Med. Kawasaki, Kanagawa 216, Japan **Dept. Physiol., Univ. Virginia Health Sci. Center, Charlottesville, VA 22908

In skeletal muscle creatine kinase (CK) plays a key role in intracellular energy metabolism. However, the presence and function of different types of CK isoenzymes in a single muscle fiber remain to be clarified. In the present study, the activity and reaction of CK in fast and slow skinned muscle fibers from Wistar strain male rats were estimated by means of biochemical approaches. Total CK and CK-MM activities were higher in fast-twitch fiber than in slow-twitch fibers. Endurance running training induced a decrease in CK-MM activity, but no change in total CK activity. When Phosphocreatine (PCr) and MgADP were added to a skinned fiber in rigor, the tension of the fiber was apparently decreased. It is thought that this decrease of the Ca^{2+}-free-rigor tension was induced by MgATP produced via myofibril-binding CK reaction. Ca^{2+}-activated maximum tension (Pmax) was decreased with the addition of PCr to the bathing solution. The decrease of Pmax in fast-twitch fiber was higher than that in slow-twitch fiber. These results suggest that binding of CK, probably in the form of CK-MM isoenzyme, to myofilaments is important not only for removing ADP from the area around the myosin crossbridge, but also for providing ATP, and that this function is more efficient in fast-twitch fibers, which have higher activity of CK-MM, than slow-twitch fibers. This work supported by grant from the Kanagawa Academy of Science and Technology.

33.13

EFFECT OF RESISTANCE EXERCISE ON POSTEXERCISE ENERGY EXPENDITURE AND SUBSTRATE UTILIZATION. C. A. Scholl*, R. Bullough*, and C. Melby. Department of Food Science and Human Nutrition, Colorado State University, Ft. Collins, CO 80523

We compared within the same 9 male subjects (aged 20-35 yrs) the effect of a bout of weight lifting versus a control condition on recovery energy expenditure, postprandial thermogenesis (PT) and resting metabolic rate (RMR). The following protocol was followed by all subjects for both the exercise and control condition. RMR was measured at 0630 h which was then followed by a standard breakfast at 0800 and lunch at 1130 h. At 1430 h the subject engaged in a strenuous 100 min bout of upper and lower body resistance exercise or quiet sitting. Immediately following both exercise and control conditions, energy expenditure was measured for two hours. Subjects were then fed a standard mixed meal and PT was measured for three hours. The following mornining, RMR was again measured at 0630 h. Energy expenditure remained elevated for the entire two-hour recovery period accounting for an average of 33 extra kcal. Total 3-h PT was higher (x=+14 kcal) following exercise compared to the control condition. A two way (time by condition) within subjects ANOVA showed that RMR measured 14 h after resistance exercise was significantly increased (x=+4.6 kcal/h) compared to the control condition. The respiratory exchange ratio the morning following exercise was significantly lower than the morning before exercise. These results suggest that strenuous resistive exercise may have a prolonged residual effect on energy expenditure and substrate utilization.

33.14

CONTINUOUS VERSUS INTERMITTENT WORK: A QUANTITATIVE APPROACH TO ENERGY EXPENDITURE. Christopher B. Scott. (SPON: N. F. Gordon). The Cooper Institute for Aerobics Research, Dallas, TX 75230.

Traditional exercise prescriptions emphasize the importance of continuous steady rate energy expenditure. Few data exist however, comparing the total energy expenditure of a continuous, steady rate exercise bout with that in which energy expenditure is intermittent in nature. To investigate this, ten women (26±3 yrs) performed two types of equivalent treadmill work at 3.3 mph and a 10% grade (62%±7 of max VO_2). Work involved both a continuous 30-min walk (CON) on one day and, six 5-min intermittent walks (INT) throughout another day. The measurement of total energy expenditure included oxygen deficit (an anaerobic metabolic measure, OD), exercise oxygen uptake (VO_2), and excess post-exercise oxygen consumption (EPOC) values. EPOC values were collected until they fell below a previously measured standing, resting oxygen uptake. When utilizing all OD, VO_2 and EPOC data, total energy expenditure was significantly larger for INT (964 kj) versus CON (877 kj) ($p=0.05$). The work required to perform both treadmill walks was equivalent and resulted in a similar energy expenditure when using VO_2+OD (INT=842 kj, CON=854 kj) or, VO_2+EPOC data (INT=871 kj, CON=861 kj) ($P=0.89$). These data indicate that when OD, VO_2 and EPOC are all taken into consideration, INT total energy expenditure is greater than CON total energy expenditure.

33.15

TRAINING EFFECTS ON GLUCOSE AND LACTATE KINETICS IN EXERCISING HORSES. E.K. Birks, J.H. Jones, T.R. Hughes, B.L. Smith, and A.L. Edinger. VM: Physiological Sciences, Univ. California, Davis, CA 95616

We tested the hypothesis that a 12-week exercise training program alters the relative contributions of aerobic and anaerobic metabolism to total metabolic power during exercise. Thoroughbred horses ran on a level treadmill at a speed sufficient to elicit $\dot{V}_{O_2max}$ (13 m·s^{-1}) while ^{14}C-labeled glucose, lactate, or bicarbonate was infused intravascularly to determine the plasma turnover rates of these compounds. Three repetitions of the exercise protocol, with infusion of only one of the radioactive compounds during a given run, were done before and after training. Mixed venous blood samples showed that plasma turnover rates of glucose and lactate increased as running speed increased. Following training, $\dot{V}_{O_2}$ and glucose turnover rates were higher, plasma lactate accumulation rates were lower, but plasma lactate fluxes were unchanged in horses running at 13 m·s^{-1}. These findings indicate that, at the same exercise intensity, training leads to increased aerobic metabolism while net anaerobic metabolism decreases. Because plasma lactate accumulation rates decreased, while plasma lactate fluxes were unchanged, either lactate production diminished with training or more lactate was being oxidized locally without contributing to the circulating pool. Biopsies from the middle gluteal muscle, taken prior to running and immediately after running at 13 m·s^{-1}, showed that, following training, muscle glycogen concentrations were higher both before and after exercise, while glycogen depletion during exercise decreased. These studies suggest that increased glucose turnover following training may not only provide oxidizable substrate for the increased $\dot{V}_{O_2}$, but also slow the rate of utilization of intramuscular glycogen, thus potentially enhancing exercise performance. Supported by the UCDavis Equine Research Laboratory, NIGMS, and the Am. Assoc. of Equine Practitioners.

LACTATE METABOLISM

34.1

LACTATE UTILIZATION BY RAT GASTROCNEMIUS MUSCLE: ANALYSIS BY ^{13}C MAGNETIC RESONANCE. Loren A. Bertocci, Gail Thomas*, Paul R. Anderson*, John G. Jones*, Ronald G. Victor, and Craig R. Malloy. UT Southwestern, Dallas TX 75235-9085.

Although it is known that skeletal muscle utilizes lactate during exercise, the precise biochemical details remain poorly understood. Isotopomer analysis of ^{13}C magnetic resonance spectra provides a powerful tool to examine how skeletal muscle utilizes exogenous lactate during both steady and non-steady state exercise. Analysis is based on the incorporation of label into glutamate, in chemical equilibrium with the TCA cycle intermediate α-ketoglutarate, and provides information about the pathways by which labeled lactate is incorporated into the TCA cycle. In this study, 5.5 mmol [3-^{13}C]lactate and 4.5 mmol [1,2-^{13}C]acetate were infused into rats during the final 30 min. of 35 and 95 min. periods of sciatic nerve stimulation of one set of hindlimb muscles, with contralateral muscles as unstimulated controls. Incorporation of the labeled lactate into the TCA cycle increased from 15.7% to 24.8% and 45.9% during rest, after 35 and 95 minutes of stimulation respectively. At the same time, incorporation of labeled acetate declined from 54.4% to 39.7% and 30.9%; thus contribution from unlabeled sources was 29.9%, 35.5% and 23.2%. Although there were great increases in the size of the peaks arising from anaplerotic enrichment of succinate, the percent incorporation of label via anaplerotic versus oxidative pathways actually decreased from 17.3% to 4.9% and 1.3%. In summary: 1) lactate was oxidized by exercising skeletal muscle; 2) fractional lactate incorporation into the TCA cycle increased with exercise and exercise duration; 3) the regulation of energy metabolism during exercise may involve incorporation of lactate into the TCA cycle via anaplerosis.

34.2

ALTERATIONS IN THE RATING OF PERCEIVED EXERTION AT THE ONSET OF BLOOD LACTATE ACCUMULATION. Jeffrey A. Potteiger and David R. Hopkins*. Indiana State University, Terre Haute, IN 47809.

Heart rate (HR) and rating of perceived exertion (RPE) have been suggested as indicators of the lactate threshold (LT) and the onset of blood lactate accumulation (OBLA). The purpose of this study was to examine if HR and RPE were markers of the LT and OBLA. Thirteen (7 male, 6 female) trained runners performed an incremental treadmill test to determine the LT and OBLA. Subjects were tested four times during training, with each test occurring 4 weeks apart (T1, T2, T3, T4). A doubly multivariate repeated measures (MANOVA) design was used for statistical analysis. There were no significant differences ($p \leq 0.05$) in HR, RPE and VO_2 at the LT. A significant difference was found for HR, RPE and VO_2 at the OBLA ($P \leq 0.17$). Post-hoc tests revealed significant differences for RPE at OBLA (T1 vs T3; T1 vs T4; T2 vs T3; T2 vs T4 $p \leq 0.05$). No differences in HR or VO_2 were observed. The data suggest that HR may be a marker of the LT and OBLA. RPE may be used to identify the LT, however it is not a good indicator of OBLA. Changes in peripheral or central perception of effort during training may be responsible.

34.3

EFFECTS OF SODIUM LACTATE INFUSION ON THE RELATION BETWEEN PLASMA pH, K^+, AND VENTILATION DURING INCREMENTAL EXERCISE. Martin W. Busse and Antje Stibbe (SPON:G. Gros). Center of Physiology, Department of Sports and Exercise Physiology, Medizinische Hochschule Hannover, D-3000 Hannover, Germany

We have examined the effects of constant rate infusions of sodium lactate (L_1: 0.792 molar, 750 ml per hour; L_2: 0.832 molar, 999 ml per hour) and saline (0.792 molar, 750 ml per hour) on the relationship between ventilation ($\dot{V}_E$), plasma potassium concentration ($[K^+]_P$), blood lactate concentration ($[Lac^-]_B$), and plasma pH (pH_P) in 5 trained cyclists in two successive incremental bicycle tests with a 7 min intervening recovery. Though pH_P and $[Lac^-]_B$ were significantly higher during the sodium lactate infusions, $\dot{V}_E$ and $[K^+]_P$ changes were almost equal in all trials. A marked pH_P increase in the B-tests, which reached alkalotic values in L_2 at maximum workload, did not affect $\dot{V}_E$ or $[K^+]_P$ either, in relation to the A-tests, where pH_P decreased throughout the test. The workload corresponding to the $[Lac^-]_B$ minimum in the B-tests, was independent of the respective $[Lac^-]_B$ or pH_P. The results indicate that a $[Lac^-]_B$ minimum determined in an incremental exercise test after an exercise induced increase in $[Lac^-]_B$, may be used to detect the respective individual equilibrium between $[Lac^-]_B$ appearance and disappearance during exercise. The findings further demonstrate that acidosis and the lactate anion have no apparent effect on exercise ventilation and $[K^+]_P$ changes, whereas the idea, that a potassium increase in interstitium or plasma may contribute to exercise ventilation, was supported by the results.

34.4

DETERMINATION OF THE LACTATE EQUILIBRIUM DURING INCREMENTAL EXERCISE TESTS: INFLUENCE OF INCREMENT SIZE, TIME AND PRECEDING LACTIC ACIDOSIS.
Uwe Tegtbur and Martin W. Busse (SPON: G. Gros). Center of Physiology, Department of Sports and Exercise Physiology, Medizinische Hochschule Hannover, D-3000 Hannover, Germany.

During an incremental exercise test (0.33 m·s^{-1} increments every 800m) after a preceding bout of maximum anaerobic exercise, blood lactate initially decreases to an individual minimum and then again increases. The speed corresponding to this individual lactate minimum (LMS) represents an individual equilibrium between lactate production and catabolism during constant load exercise, i.e. a maximum steady state intensity. Only a slight speed increase above the LMS would result in a continuous marked blood lactate concentration ($[Lac^-]_B$) increase and earlier exhaustion. To examine the influence of the test protocol on the LMS the following field tests were performed: Series 1. Variation of the increment size, 0.2 and 0.33 m·sec^{-1}, in 13 males showed no change of the LMS (4.23 and 4.27 m·sec^{-1}). Series 2. Variation of the increment length in 13 males showed no change of the LMS using 800 and 1200 m increments (4.49 and 4.44 m·sec^{-1}) and a marked shift to higher speed using 400 m increments (4.96 m·sec^{-1}). Series 3: Effects of different $[Lac^-]_B$, i.e. normal ("N) and low ("L") muscle glycogen stores on the LMS were determined in 10 males. Though $[Lac^-]_B$ was significantly different (14.1 in N and 10.6 mmol·l^{-1} in L after preceding bout of maximum exercise; $p < 0.01$; 3.7 in N an 3.1 mmol·l^{-1} in L at the lactate minima), no difference of the LMS with normal or low muscle glycogen stores was found. It appears that the LMS may used to determine the "anaerobic threshold" independently of the muscle glycogen stores.

34.5

IS THE RELATIONSHIP BETWEEN [LAC] AND POWER SUPERIOR TO VO_{2max} TO DETERMINE ENDURANCE PERFORMANCE? N. Maassen*, G. Schneider*, M.W. Busse* (SPON: G. Gros), D-3000 Hannover, FRG.

It is generally accepted that endurance trained subjects (TR) can perform longer at exercise intensities corresponding to the same percentages of $\dot{V}O_2$max than untrained subjects (UT). This is often explained with an increase of the anaerobic metabolism only at high percentages of $\dot{V}O_2$max. On the other hand [Lac] during exercise $\dot{V}O_2$max and endurance time are dependent on the glycogen content of the muscle. Thus the above cited opinion might be deduced from experiments, in which no attention was payed to the glycogen content of the muscles. Methods: 11 TR and 11 UT participated in the study. First test (after 2 days without training): incremental test to determine $\dot{V}O_2$max and the relation between [Lac] and power, followed by 3 days of glycogen loading (Saltin diet). On the forth day the constant load experiments at various percentages of $\dot{V}O_2$max . Until subjective exhaustion were performed. $\dot{V}O_2$, heart rate, and [Lac] were measured. Results: TR and UT worked at 81.6 +/- 21.1 % and 80.0 +/- 9.6 % respectively. The performance times were almost the same (52.82 min). There is no significant correlation between [Lac] during exercise and the performance time. The highest correlation was between the percentage of $\dot{V}O_2$max and performance time: (%$\dot{V}O_2$max = 128.4 - 12.67 * ln (perf. time); R = 0.94). Conclusions: TR and UT can perform for similar times at the same percentage of $\dot{V}O_2$max. The above cited opinion is perhaps due to different fillings of the glycogen stores. For the superiority of the determination of the endurance capacity by means Lactate thresholds above $\dot{V}O_2$max there is no physiological basis.

34.6

THE EFFECTS OF "SPONTANEOUS RELAX MOVING QIGONG" ON LACTIC ACID CAPACITY AND EXERCISE PERFORMANCE. Ren Jiansheng and Shi Aiqia*. Dept. of Physiology, Wuhan Institute of Physical Education, Wuhan, 430070, PRC

We use the "Spontaneous Rela Moving Qigong" (SRMQ) for a duration of 25-30min as a warmup to compare with the exercise warmup(EW) for a same duration to observe the effects of the SRMQ on lactic acid capacity and exercise performance. Fourteen male college students(major in physical Ed.$\bar{x}$ age = 20.1)who trained SRMQ for two months took part in this study. A step-wise incremental cycle ergometer test(initial work rate 230W,30 sec,30W step)until exhaustion was used to measure maximal work rate(WR)and work time(WT)after the SRMQ practice and the EW on different days. VE, $\dot{V}O_2$ and RQ were obtained breath by breath by a computerized system. Blood lactate(BL)was measured respectively before and after the cycle ergometer test. The 800 M run at full effort was measured in athletic field after the SRMQ practice and the EW on different days. The following results were obtained.

After	WR(W)	WT(sec)	800M(sec)	BL(mM)	VO_{2max}(L)
SRMQ	320±12.2	90.6±14.3	134.2±5.2	18.3±1.6	2.97±0.41
EW	296±14.6	82.5±20.7	140.3±6.1	15.8±1.8	3.01±0.33

* * *

The VE, RQ and VO_{2max} during cycle ergometer test did not differ significantly between after the SRMQ practice and after the EW. It was concluded that use the SRMQ as a warmup could effectively improve lactic acid capacity and exercise performance.

34.7

BLOOD [LACTATE] AND 'EXCESS' O_2 UPTAKE DURING HIGH-INTENSITY CYCLING AT SLOW AND FAST CADENCES. G.A. Gaesser, R.J. Cooper* and L.A. Wilson*. Exerc. Physiol. Lab., Univ. of Virginia, Charlottesville, VA 22903 and Dept. of Kinesiology, UCLA, Los Angeles, CA 90024.

At work rates (WR) above the lactate threshold (LT), $\dot{V}O_2$ increases above that projected from the sub-LT relationship, giving rise to an 'excess' $\dot{V}O_2$. During cycle ergometry exercise (CE) at relatively slow cadences, the 'excess' $\dot{V}O_2$ is a function of both relative work rate and time, and is well correlated with the rise in blood [lactate]. In the present study we sought to determine whether high-intensity CE at a fast cadence would alter the relationship between 'excess' $\dot{V}O_2$ and blood [lactate]. Nine healthy males performed two, supra-LT, constant-power exercise bouts of 18 min duration: one at 50 rpm and one at 100 rpm (same absolute power, averaging 186 ± 10 W). Ventilatory and pulmonary gas exchange were measured breath-by-breath and blood was sampled for [lactate]. For all subjects, terminal (min 18) $\dot{V}O_2$ was higher ($P<0.01$) at 100 rpm (3.49 ± 0.22 l·min^{-1}; 80.7 ± 2.9 %$\dot{V}O_2$peak) compared to that at 50 rpm (2.80 ± 0.17 l·min^{-1}; 67.3 ± 3.0%$\dot{V}O_2$peak). 'Excess' $\dot{V}O_2$ ($\dot{V}O_2$ at min 18-min 3) also was higher ($P<0.01$) at 100 rpm (0.67 ± 0.11 l·min^{-1}; range = 0.24 to 1.25 l·min^{-1}) compared to that at 50 rpm (0.34 ± 0.07 l·min^{-1}; range = 0.14 to 0.85 l·min^{-1}), as was terminal blood [lactate] (8.2 ± 0.9 mM vs. 5.4 ± 0.8 mM). 'Excess' $\dot{V}O_2$ was significantly correlated with terminal blood [lactate] at both 50 rpm ($r = 0.96$) and 100 rpm ($r = 0.73$), as well as for both conditions combined ($r = 0.86$). We conclude that the 'excess' $\dot{V}O_2$ of high-intensity CE 1) is influenced by cadence as well as WR, 2) may be increased by ~100% while exercising at fast vs. slow rpm, and 3) is highly correlated with the systemic rise in blood [lactate] regardless of cycling cadence.

34.8

BLOOD LACTATE AND AND CATECHOLAMINE RESPONSES TO INCREMENTAL ROWING AND TREADMILL RUNNING. A. Weltman, C.M. Wood, C.J. Womack, S.E. Davis, J.L. Blumer* and G.A. Gaesser. Exercise Physiol. Lab., Univ. of Virginia, Charlottesville, VA 22903.

Ten collegiate rowers performed discontinuous, incremental exercise to their tolerable limit on two occasions: once on a rowing ergometer (Concept II) and once on a treadmill. Ventilatory and pulmonary gas exchange were monitored continuously, and blood was sampled from a venous catheter located in the back of the hand or in the forearm for determination of blood [lactate] and plasma epinephrine [epi] and norepinephrine [norepi]. Thresholds for lactate (LT), epinephrine (ET), and norepinephrine (NET) were determined for each subject under each condition, and were defined as 'breakpoints' when plotted as a function of $\dot{V}O_2$. The thresholds were, in l·min^{-1}:

Mode	LT	ET	NET
Rowing	3.35 ± 0.16	3.72 ± 0.22	3.70 ± 0.18
Running	3.76 ± 0.18	4.35 ± 0.14	4.04 ± 0.19

For both modes, the LT preceded ET and NET in ~70% of the cases, and suggested that catecholamine 'thresholds', per se, were not the cause of the LT. However, in all instances the LT occurred at plasma [epi] of ~200-250 pg·ml^{-1} (221 ± 48 pg·ml^{-1} for rowing; 245 pg·ml^{-1} for running), which is consistent with the [epi] threshold for eliciting increments in blood [lactate] (Clutter et al., J. Clin. Invest. 66: 94-101, 1980). Plasma [norepi] at the LT differed significantly between modes (820 ± 127 pg·ml^{-1} rowing vs. 1712 ± 217 pg·ml^{-1} running). We conclude that although the lactate and epinephrine 'thresholds' (as defined herein) may not occur at the same $\dot{V}O_2$, the observation that the LT always occurred at plasma [epi] of ~ 220-250 pg·ml^{-1} is consistent with the hypothesis that plasma [epi] plays a causal role in the LT.

34.9

MALE - FEMALE DIFFERENCES IN ANAEROBIC PERFORMANCE - *BIOLOGICAL* OR BEHAVIOURIAL? A.M. Batterham and K.P. George. Division of Sports Science, Crewe and Alsager College of Higher Education, Alsager, ST7 2HL, ENGLAND.

The purpose of this study was to compare the maximal anaerobic power during leg and arm ergometry, of 13 pairs of men and women matched for habitual physical activity via questionnaire. External Peak Power Output (PPO) was derived from the Wingate 30 s Anaerobic Test (WANT) on a friction-braked ergometer. In addition, Body Mass (BM), Lean Body Mass (LBM and the estimated anatomical cross-sectional areas (XSA) of upper arm and thigh muscles were determined via anthropometry. Absolute PPO was greater in males than in females for both legs and arms (1252± 270 vs. 681± 96 W, and 523± 119 vs. 214± 72 W respectively; $p< 0.05$). The ratio standards PPO/BM and PPO/LBM were also significantly different between men and women for both legs and arms ($p< 0.05$). The ratio standard PPO/XSA did not differ significantly between males and females for either arm or leg tests (7.1± 2.0 vs. 5.8± 1.1, and 10.4± 2.4 vs. 8.5± 2.9 W. [cm2]$^{-1}$, respectively; $p> 0.05$). Comparison of the regression standards via Analysis of Covariance (ANCOVA) however, with BM, LBM and XSA as covariates, revealed significant inter-group differences for both arm and leg PPO ($p< 0.05$). Via Multiple Regression and subsequent beta weights analysis, GENDER was found to be the only significant predicator of both arm and leg PPO ($p< 0.05$). The results suggest that true biological sex differences exist in arm and leg PPO, independent of body size, composition or active muscle mass. The findings also demonstrated that a consideration of ratio standards was misleading and that ANCOVA techniques comparing regression standards are more valid and meaningful.

34.10

THE EFFECT OF BLOOD SAMPLING SITE ON LACTATE CONCENTRATION DURING GRADED AND CONSTANT-SPEED TREADMILL RUNNING. K.P. George, M.S. El-Sayed and K. Dyson*. Division of Sport Science, Crewe and Alsager College, Alsager, ST7 2HL, ENGLAND.

The purpose of this study was to examine the lactate concentration ([LA]) differences between fingertip (FT) and venous (VN) blood during graded and constant-speed exercise in eight healthy, active subjects. FT and VN blood [LA] were determined pre-exercise and in response to graded treadmill exercise. Data indicated that FT blood [LA] were significantly higher than VN blood [LA] prior to exercise and at all treadmill speeds ($p< 0.05$). Furthermore, the difference in [LA] between FT and VN blood was exercise intensity related ($p< 0.05$). The running speed required to elicit a blood [LA] of 4 mmol.L^{-1} was significantly higher when VN blood was used compared to FT blood ($p< 0.05$). Seven subjects then completed two thirty minute submaximal treadmill runs at speeds predicted to elicit 4 mmol.L^{-1} blood [LA] from FT and VN blood sampled in the graded exercise test. FT and VN blood was drawn after 5, 10, 20, 30 minutes of exercise and 5 minutes into recovery. Data indicated that the FT blood [LA] were also significantly greater than VN blood [LA] in constant-speed running and recovery ($p< 0.05$). Furthermore, data indicated that there was a significant increase in blood [LA] as a function of time. It is concluded that sampling site differences in blood [LA] should be considered when [LA] determination is employed as a criteria to evaluate and predict performance. Also, the blood [LA] and performance response to both of the submaximal exercise treadmill runs must question the validity of the 4 mmol.L^{-1} [LA] as an exercise intensity/performance predictor.

34.11

BLOOD LACTATE CONCENTRATION DURING SUBMAXIMAL CONSTANT WORK LOAD UNDER HYPERBARIC OXYGENATION.

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Five triathletes (21 to 49 yrs) performed submaximal constant load tests (15 min) on a cycle ergometer under normobaric normoxic conditions (NN) and under 100 % O_2, 1.5 bar oxygenation (HBO). At given ranges of load intensity (A, B, C) blood lactate concentrations (BLC) were 1.7 ±0.5 $mmol \cdot l^{-1}$ (A), 2.5 ±0.2 $mmol \cdot l^{-1}$ (B), and 4.4 ±0.9 $mmol \cdot l^{-1}$ (C) under NN, and 1.7 ±0.2 $mmol \cdot l^{-1}$ (A), 2.0 ±0.2 $mmol \cdot l^{-1}$ (B), and 2.3 ±0.2 $mmol \cdot l^{-1}$ (C) under HBO. At load intensity C, the difference in BLC between NN and HBO was significant ($p<0.01$). The effect of HBO on BLC depends on load intensity.

34.12

EFFECT OF FIO_2 ON ACID RELEASE FROM THE EXERCISING LEG AT $\dot{V}O_{2MAX}$.

D.R. Knight, D.C. Poole, M.C. Hogan, D.E. Bebout, and P.D. Wagner. University of California, San Diego, La Jolla, CA, 92093-0623.

We have reported (Knight et al. FASEB J. 6:A1466, 1992) that peak work rate (WR_{MAX}) and leg $\dot{V}O_{2MAX}$ are increased by raising the concentration of inspired O_2 (FIO_2). The effect of FIO_2 on work rate led us to expect greater release of lactate and H^+ from the leg at higher WR_{MAX}. Eleven men performed cycle exercise to maximal effort at FIO_2's of 0.12, 0.21, and 1.00. Catheters in the radial artery and femoral vein enabled us to measure leg blood flow and venoarterial differences in blood concentrations of lactate ($[L]_{DIFF}$) and H^+ ($[H^+]_{DIFF}$). Maximal leg blood flow (2X 1-leg blood flow = 19.4±0.5 $L \cdot min^{-1}$) was not affected by FIO_2. Therefore, $[L]_{DIFF}$ and $[H^+]_{DIFF}$ were used as indicies of acid release from the exercising leg. Linear regression analyses showed that increases in mean WR_{MAX} from 287 to 401 W (as FIO_2 was raised from 0.12 to 1.00) decreased the $[L]_{DIFF}$ from 1.32 to 0.95 mM (slope = -0.0024±0.0009 $mM \cdot W^{-1}$; $p=0.03$), yet increased the $[H^+]_{DIFF}$ from 28.0 to 37.4 nM (slope = 0.094±0.009 $nM \cdot W^{-1}$; $p<0.001$). There was a corresponding decrease in arterial pH of 0.0006 $Units \cdot W^{-1}$ ($p<0.001$). The increased $[H^+]_{DIFF}$ and lower blood pH are likely due to enhanced aerobic production of CO_2 at higher WR_{MAX}. The surprising reduction in $[L]_{DIFF}$ at higher work rates may be due to several mechanisms, one of which is the impedence of lactate release by *higher $[H^+]$ in the* blood.

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34.13

MAXIMAL RATE OF BLOOD LACTATE ACCUMULATION DURING HIGH ALTITUDE EXPOSURE IN HUMANS.

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The reduction of maximal lactic capacity with altitude exposure may depend on a decreased substrate flow through the glycolytic pathway. If this is the case, provided unchanged blood lactate kinetics at the end of exercise, the maximal rate of blood lactate accumulation should be decreased at altitude. To test this hypothesis, 6 males (32±4 years, x±SD) performed cycloergometric exercises of increasing duration up to exhaustion (30-45 s) at 200% of $\dot{V}O_2$max, at sea level (SL1), after 7 (ALT1) and 27 (ALT2) days at 5050 m (Ev-K2-CNR Pyramid), and 7 days after return to sea level (SL2). On day 27, the subjects exercised also after ingestion of 0.3 g/kgBW of $NaHCO_3$ (ALT2-$NaHCO_3$), as well as at a work load corresponding to $\dot{V}O_2$max at ALT2 plus $\dot{V}O_2$max at SL1 (ALT3). Lactate accumulation in blood ($\Delta[La_b]$) was determined for each exercise bout. After exhaustion, the kinetics of La_b appearence and disappearence were followed during recovery. $\Delta[La_b]$ was linearly related to exercise duration. The slopes of the individual regression lines, equal to the maximal rate of blood lactate accumulation ($\Delta[La_b]/\Delta t$), were lower at ALT1 (0.09±0.02) ($P<0.01$) and at ALT2 (0.17±0.05) ($P<0.05$) than at SL1 (0.25±0.05) and SL2 (0.23±0.06). There was no difference between ALT2, ALT2-$NaHCO_3$ (0.16±0.05) and ALT3 (0.17±0.05). The kinetics of appearance and disappearance of $[La_b]$ in the recovery were similar in all conditions. In conclusion, $\Delta[La_b]/\Delta t$ is reduced by altitude exposure. Such reduction, which is less marked after 27 days of acclimatization and independent of buffer capacity, is compatible with the hypothesis of a reduced substrate flow through the glycolytic pathway at altitude.

This research was supported by the Swiss Federal Sport Committee and the Italian Ev-K2-CNR project.

34.14

PEAK BLOOD LACTATE CONCENTRATION AND BLOOD BUFFERING CAPACITY DURING HIGH ALTITUDE ACCLIMATIZATION AND DEACCLIMATIZATION IN HUMANS.

B.Grassi,^ B.Kayser,^ M.Marzorati, A.Colombini,* C.Marconi,* and P.Cerretelli, ITBA of CNR, Milan, Italy; Dept. of Physiology, CMU, University of Geneva, Switzerland

Prolonged high altitude exposure leads to a reduction in peak blood lactate concentration after exhaustive exercise ([Lab]p). The time course of this reduction during acclimatization, as well as that of the increase in [Lab]p following return to sea level (sl), and their relationship with blood buffering capacity have not been described so far. To this aim, 10 males (32±4 years, x±SD) performed incremental cycloergometric exercises up to exhaustion at sl before departure (SL1); after 11 (ALT1), 24 (ALT2), 31 (ALT3) days at 5050 m (Ev-K2-CNR Pyramid,); and 1, 2, 3, 4, 5 weeks after return to sl (SL2, SL3, SL4, SL5, SL6). At ALT1 and ALT3 5 subjects were also tested in acute hypobaric normoxia (ALT1O2 and ALT3O2). [Lab] was determined in earlobe blood at rest and in the recovery after exercise. pH and PCO2 were assessed in resting arterialized blood. [Lab]p (mM) decreased from 11.5±2.2 at SL1 to 8.0±3.0 at ALT1, 6.4±1.4 at ALT2, 6.3±0.9 at ALT 3. It increased to 8.0±1.9 at SL2, 9.4±1.7 at SL3, 10.8±1.4 at SL4, 11.3±2.6 at SL5, 11.6±2.2 at SL6. No significant difference in [Lab]p was observed between ALT1 and ALT1O2 (7.2±1.8), nor between ALT3 and ALT3O2 (6.3±1.1) 3) Blood pH increased from 7.41±0.02 at SL1 to 7.47±0.02 at ALT2, slightly decreased to 7.45±0.03 at ALT3, and returned to 7.40±0.02 at SL2. It is concluded that [Lab]p keeps decreasing during the first 2-3 weeks of acclimatization to altitude. The kinetics of this decrease has the same time course as the increase observed after return to sl. [Lab]p during acclimatization and deacclimatization seems not related to PIO2 nor to the blood acid-base status.

This research was supported by the Swiss Federal Sport Committee and the Italian Ev-K2-CNR project.

34.15

RELATION OF MUSCLE GLYCOGEN CONTENT TO MAXIMUM ANAEROBIC POWER AND TO AEROBIC RECOVERY RATE.

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Small lizards (Anolis carolinensis) were forced to work maximally at 32°C for from 5 sec to 3 min. Each was then homogenized within 5 sec following work and analyzed for lactate. From the rate of lactate rise, the rate of glycogen loss was found to be logarithmic (first order) at 2.5% /sec. Since maximum exertion exhausts muscle glycogen in about the same time in mammals as in reptiles, and since muscle glycogen contents are similar, peak anaerobic power/kg is similar also. As the glycolytic curve is first order, peak anaerobic power/kg is directly proportional to initial glycogen content. The rate of recovery (aerobic gluconeogenesis) proved first order also, indicating that the higher the initial glycogen content the faster the recovery rate. Following work, oxygen consumption was highest at the lactate peak. As lactate fell oxygen usage fell indicating that substrate (lactate) concentration determined (in part) the rate of gluconeogenesis and therefore O_2 demand for ATP production. As substrate delivery limits gluconeogenesis, blood flow is rate limiting. Supported by Louisiana Department Wildlife and Fisheries.

34.16

A COMPARISON OF PYRUVATE-LACTATE KINETICS IN MUSCLE AND GUT.

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We have recently developed a new model to derive pyruvate and lactate kinetics across an organ in vivo based on the systemic continuous infusion of pyruvate or lactate stable isotopic carbon tracers and the measurement of the pyruvate and lactate enrichment and concentration in the artery and vein of that tissue, the pyruvate and lactate enrichment of intracellular free water in the tissue as measured by biopsy, and the rate of blood flow through the tissue. The purpose of this experiment was to compare the pyruvate-lactate kinetics in leg muscle and gut in anesthetized dogs (n=6). Results: The transmembrane transport and degree of shunting of pyruvate and lactate were comparable in muscle and gut. Interconversion between pyruvate and lactate in muscle took place at a rate twice as fast as the interconversion in the gut. Production and oxidation of pyruvate in muscle was approximately 50% greater than the production and oxidation of the gut when normalized for substrate inflow to the tissue. We conclude that even in anesthetized animals the muscle is the tissue most responsible for whole body peripheral pyruvate-lactate kinetics.

34.17

LACTATE KINETICS IN HUMANS DURING EXERCISE: MEASUREMENT OF MUSCLE INTRACELLULAR LACTATE ENRICHMENT. Bradley D. Williams, Ingrid Plag, John Troup, and Robert R. Wolfe. Shriners Burns Inst., Univ. of Tx. Medical. Branch, Galv., Tx. 77550, and Int. Cen. for Aq.Res., Colo Springs, Co.80809.

The traditional use of tracers to quantify lactate-pyruvate kinetics assume that blood tissue measurements reflect tissue measurements. However, the relationship between blood and tissue enrichments has not previuosly been determined in humans. In this study, four healthy male subjects exercised at 40%(10min), 75%(30min), and/or 95% VO_2max(4-6min), following a 90 min rest period. U^{13}C-Pyruvate was infused in the vein, arterialized blood was drawn throughout, and concomitant muscle biopsies (<20sec.) were taken at or near plasma isotopic steady-state at the end of each period. The muscle intracellular lactate Δtracer/tracee ratio was consistently ~80% lower than the circulating lactate Δtracer/tracee ratio in all the above conditions (see table).

Study Period	Infusion Rate (μmol/kg·min)	[1]*LA_M / *LA_P (Mean ±SE)
Rest (n=5)	0.5	0.18±0.04
40% VO_2max (n=3)	2.0	0.16±0.02
75% VO_2max (n=2)	7.5	0.19±0.02
95% VO_2max (n=3)	7.5	0.19±0.02

[1]Plasma lactate enrichment-*LA_P and muscle intracellular lactate enrichment-*LA_M.

We conclude that the enrichment of circulating lactate does not reflect muscle intracellular enrichment and that blood sampling alone may not be adequate for the quantification of pyruvate-lactate kinetics.

34.18

EFFECT OF LACTATE TRANSPORT INHIBITORS ON UNIDIRECTIONAL LACTATE INFLUX INTO SKELETAL MUSCLE. L. Bruce Gladden, Robert E. Crawford, Michael J. Webster, and Peter W. Watt*. Dept. of Health & Human Performance, Auburn Univ., Auburn, AL 36849 and Dept. of Anat. and Physiol., Univ. of Dundee, Dundee, Scotland DD1 4HN.

This study examined lactate (HLa) influx into dog gastrocnemius muscle (GP) during exposure to HLa transport inhibitors. In situ GPs of 25 anesthetized dogs were perfused with red cell-free media (Krebs-Henseleit, 8 g% dextran, 5 mM glucose, pH = 7.3, 1 mM HLa). Influx was measured by a paired-tracer dilution method (Watt et al., BBA 944:213-222, 1988). Pyruvate at 25 mM inhibited tracer HLa uptake to the same extent (52.8%) as did 25 mM HLa (47.4%). DIDS (4,4'-diisothiocyano-stilbene-2,2'-disulfonic acid-0.1 mM) had no effect on HLa influx. Phloretin, a putative HLa transport blocker, had no effect on HLa influx at 0.6 mM, but reduced the % Uptake of HLa by 25.8% at 1.5 mM. Influx was not consistently blocked by α-cyano-4-hydroxy-cinnamate (Cin) at 10 and 20 mM, but at 45 and 50 mM decreased HLa %Uptake by 53-77%. The organic mercurial, p-chloromercuribenzenesulphonic acid (PCMBS), had no consistent effect on HLa influx at 0.1-0.3 mM; but reduced influx at 0.4 and 0.5 mM. HLa influx did not return to control values after 1.5 mM phoretin, and the GP increased resistance to perfusate flow and developed edema at concentrations of Cin and PCMBS which decreased %Uptake of HLa. In conclusion, these results support the role of a membrane carrier for HLa in skeletal muscle, but suggest that some HLa transport blockers may not be as specific in situ as in vitro.

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34.19

LACTATE TRANSPORT IN RAT SKELETAL MUSCLE. Karl J. McCullagh*, John C. McDermott* and Arend Bonen. Dalhousie University, Halifax, N.S. B3H 3J5; Harvard Medical School, Boston, Mass.; University Of Waterloo, Waterloo Ontario, N2L 3G1.

To determine the nature of the membrane permeability to L-lactate, the transmembrane flux of lactate was studied in purified skeletal muscle plasma membrane vesicles. Transport (zero-trans) in vesicles indicated saturability with increasing L-lactate concentrations, stereospecificity, and sensitivity to inhibitor compounds such as pyruvate (-81%) and N-ethylmaleimide(-86%), and stimulation by an inwardly directed proton gradient (r=-0.99, over the extracellular pH range 6.0-8.5). When these studies were performed in strips (<5mg) of rat soleus muscles incubated in vitro (45 sec) similar results were obtained (i.e.coincident L-lactate transport in muscle strips and purified membrane vesicles, and in muscle strips lacate transport i) followed a proton gradient and ii) is inhibited by pyruvate (-40%) and N-ethylmaleimide (-40%),. Electrical stimulation of the sciatic nerve (30min) increased the uptake of 2-deoxy-D-glucose (P<0.05) but failed to alter the uptake of L-lactate (P>0.05) in soleus muscle strips. After 5 weeks of training L-lacate transport (1mM) into purified plasma membrane vesicles was increased (P<0.05). Incubation of membranes with [U-^{14}C]-L-lactate labelled a membrane protein of approximately 34 kDa on SDS/PAGE. Collectively, these data suggest that a carrier-mediated transport system may be the predominant mode for lactate transport in skeletal muscle. The transport sytem is sensitive to alterations in pH and exercise training. The lacate transport system may involve a transporter protein of 34kDa in rat muscle.

Supported by the NSERC A6449

CELLULAR REGULATORY MECHANISMS

35.1

MANGANESE SUPEROXIDE DISMUTASE ACTIVITY IN HUMMINGBIRD FLIGHT MUSCLES.
Etelvino J.H.Bechara, Celina V. Zerbinatti, Jose E.P.W. Bicudo*. University of Sao Paulo, 05508-900, SP, Brazil.

The activity of manganese superoxide dismutase (Mn-SOD) is correlated with the mitochondrial volume density, V(mi,mf) in the cell, and varies between 12-18% in mammalian skeletal muscles. The percent activity of SOD-Mn in the flight muscles of the hummingbird *Eupetomena macroura* was calculated from the total-SOD and Cu,Zn-SOD activities (before and after inhibition of Mn-SOD by sodium duodecyl sulfate), measured using Fridovich's methodology. The results obtained were compared to values for V(mi,mf) and for mitochondrial inner membrane surface area, Sv(im,mi) determined by morphometric analysis in the same tissues.

	ACTIVITY, U/G TISSUE		
TISSUE	Total-SOD	Cu,Zn-SOD	% Mn/Total-SOD
Pectoralis	2271	954	58
Supracoracoideus	1620	622	62

These results show that the percent activity of Mn-SOD in relation to the total-SOD activity is 2 times higher than V(mi,mf) (28%). However, hummingbird mitochondria contain 2 times more Sv(im,mi) than mammalian mitochondria, thus in accordance with a 2 times higher Mn-SOD activity than V(mi,mf) observed in hummingbird flight muscles. These results, therefore, indicate that the Mn-SOD has a primary role in protecting the mitochondria against superoxide production during oxidative phosphorylation.

Supported by FAPESP, CNPq, CAPES (Brazil) and NIH (USA).

35.2

ANTIOXIDANT ACTION OF VITAMIN E ON EXERCISE-INDUCED LIPID PEROXIDATION AND THROMBOXANE B_2. Lynn Toohey, Mary Harris, James Sockler and Loren Cordain. Colorado State Univ., Fort Collins, Colo. 80521

In a randomized, double-blind, placebo-controlled design, ten endurance-trained male and female subjects (21-34 years) were exercised at 60% VO_2max on a bicycle ergometer for 30 minutes to determine if vitamin E supplementation would reduce thromboxane A_2 formation by suppressing hydroperoxides. Thromboxane A_2 was measured by the stable metabolite thromboxane B_2 (TxB_2) in serum. Baseline exercise-induced TxB_2 was determined by radioimmunoassay in all subjects, who were then randomly assigned to either a placebo or vitamin E (1,000 IU/day) group, and then measured again pre- and post-exercise two weeks later. Plasma vitamin E was analyzed by high performance liquid chromotography. Dietary fatty acids, vitamin E, vitamin C, kilocalories and percentage of fat, carbohydrate and protein were estimated from two seven-day dietary records and analyzed using the NutCal program. Supplementation did not significantly affect TxB_2, suggesting that free radical production was not high enough to raise lipid peroxides. However, this may have been because our subjects were highly trained.

35.3

REPETITIVE MECHANICAL STIMULATION OF TISSUE CULTURED SKELETAL MUSCLE MITIGATES GLUCOCORTICOID-INDUCED DECREASES IN $PGF_{2\alpha}$ SYNTHESIS AND PROSTAGLANDIN H SYNTHASE ACTIVITY. J.A. Chromiak, H.H. Vandenburgh, J. Shansky*, and R. Solerssi*. Department of Pathology, Brown University and The Miriam Hospital, Providence, RI 02906

Exercise *in vivo* and repetitive stretch-relaxation of tissue cultured, avian skeletal myofibers *in vitro* partially reverses glucocorticoid-induced myofiber atrophy. The stretch-induced attenuation of the dexamethasone (dex)-induced decline in protein synthesis rate *in vitro* was partially prevented by the prostaglandin synthesis inhibitor indomethacin (100 μM). Since $PGF_{2\alpha}$ is an autocrine and paracrine growth factor in skeletal muscle, we measured $PGF_{2\alpha}$ synthesis and prostaglandin H synthase (PGHS) activity in response to dex and mechanical stretch in tissue cultured skeletal muscle. Day 7 cultures were changed to serum-free medium ± 10^{-8}M dex. Culture media were collected after 24 hr for determination of $PGF_{2\alpha}$ synthesis. PGHS activity was determined by measuring $PGF_{2\alpha}$ produced after a 30 min incubation of the cultured cells with 30μM arachidonic acid. In static cultures, $PGF_{2\alpha}$ synthesis was reduced 55% after 24 hours in 10^{-8}M dex compared to controls. Mechanical stimulation increased $PGF_{2\alpha}$ synthesis 41% in control cultures. In dex-treated cultures, mechanical stimulation increased $PGF_{2\alpha}$ synthesis 162% so that $PGF_{2\alpha}$ synthesis was not significantly different from non-dex treated static or stretched controls. PGHS activity was reduced 72% in response to dex after 24 hr. PGHS activity was increased 98% in mechanically stimulated, dex treated cultures compared to dex-treated static cultures, but was still 45% less than non-dex treated static controls. These results indicate that mechanical stimulation *in vitro* may attenuate the catabolic effects of dex on skeletal muscle by reversing the dex-induced declines in PGHS activity and $PGF_{2\alpha}$ synthesis.

(Supported by NIH F32 ARO8128, RO1 AR39998, and NASA NAG2-4143.)

35.4

HEAT-INDUCED ALTERATIONS IN EPITHELIAL PERMEABILITY. C. Gapen*, M.W. Peterson*, P.L. Moseley, University of Iowa, Iowa City, IA 52242.

Exercise is a substantial stress, and when performed in the heat, thermal injury is exacerbated. The presence of endotoxemia and intestinal hemorrhage suggests that changes in epithelial permeability may be crucial in the pathophysiology of this injury. To determine whether alterations in epithelial permeability could be induced by physiologically relevant temperatures, a high resistance clone of MDCK epithelial cells was cultured on nitrocellulose filters. Epithelial barrier integrity was determined by measuring transepithelial conductance in Ussing chambers attached to a current voltage clamp. Once the monolayers were electrically stable, they were subjected to a 90 minute ramp increase in temperature from 37°C to 41°C. Permeability changes after heating were determined by measuring the transepithelial conductance throughout heating. Transepithelial electrical conductance increased when monolayers were heated $\geq$ 38.7°C ($p<0.05$). Monolayers kept at 37°C remained stable over the entire course of the experiment. Prior heating of animals has been shown to increase survival to a subsequent otherwise lethal heat stress, through a process termed thermotolerance. If increased epithelial permeability is important in the pathophysiology of heat stress, we reasoned that thermotolerance may be expressed as increased resistance of the epithelium to heat-induced barrier disruption. Following a 90 min conditioning heat stress at 41°C, the cultured monolayers tolerated approximately 1.8°C higher temperature before permeability increased compared to unconditioned monolayers. This 90 min conditioning treatment also conferred thermotolerance as measured by cell survival of a lethal 45°C heat stress (cell counts x 10^4: 37°C control = 17± .46, 45°C = 7.2± .14, 41°C alone = 13.7± .69, 41°C followed by 45°C = 12.1± .52). These studies demonstrate that small temperature elevations within the physiologic range increase epithelial permeability, and that prior heat stress shifts the threshold temperature required to disrupt the epithelium. Supported by NIH grant AR40771.

35.5

EFFECT OF HEATING RATE ON SYNTHESIS OF HSP 72. S.W. Flanagan, A.J. Ryan*, C.V. Gisolfi, and P.L. Moseley. Depts. of Exercise Science and Internal Medicine, Univ. of Iowa, Iowa City, IA 52242.

Exercise increases heat storage and can predispose an organism to thermal injury. Using 72 kd heat shock protein (HSP70) as a marker of thermal injury, we hypothesized that a high heating rate (HHR) would result in more HSP70 than a low heating rate (LHR) in passively heated animals. Rats were assigned to either control, high ($0.1461°C \cdot min^{-1}$) or low ($0.0446°C \cdot min^{-1}$) heating rate groups. Heat exposure was terminated when colonic temperature reached 42°C. Thermal load was significantly higher in the low ($28.1°C \cdot min^{-1}$) compared to the high ($18.4C \cdot min^{-1}$) heating rate group. Tissue samples were obtained from the liver, small intestine, brain, and kidney 4 h post heat and assayed for HSP70 by western blot. HHR rats had greater levels of HSP70 in the liver and small intestine compared to LHR or control groups. No increases in HSP70 were observed in the brain or kidney. To examine if these differences in HSP70 synthesis were due to differences at the organ or cellular response level, rat ileal epithelium cells (IEC) were exposed to similar high ($0.127°C \cdot min^{-1}$) and low ($0.047°C \cdot min^{-1}$) heating rates. After reaching 42°C, cells were maintained in the heat 30 min and then returned to 37°C. Cells were collected 12 h post heat stress and assayed for HSP70. Western blot analysis revealed no differences in HSP70 between high and low heating rates in the IEC. The present data suggest that HSP70 synthesis may be more closely related to the rate of heating than to the duration or magnitude of heat exposure. Furthermore, these studies reveal tissue differences in the HSP70 response to a hyperthermic stress. These differences are not reflected in isolated ileal epithelial cells subjected to *in vitro* thermal stress. Supported by NIH Grant AR40771.

35.6

ACID INSOLUBLE PURINE SUBSTANCE IN RAT SKELETAL MUSCLE. Peter C. Tullson and Ronald L. Terjung. SUNY Health Science Center, Syracuse, NY 13210

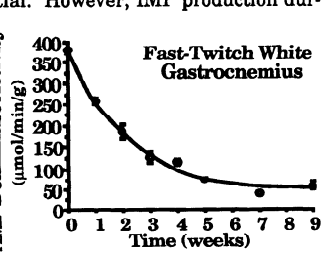
Exercise perturbs the distribution of muscle AdN and can lead to the degradation of purines to nucleosides and bases, especially when ATP utilization >> supply. Recent evidence suggests the existence of another class of purine derivative that rapidly interconverts with the adenine nucleotide pool; it is believed to be an *acid-insoluble* oligomer of ATP and phosphoglycerate (Mowbray & Patel, *Biochem. Cell Biol.* 69:583, 1991). Acid extractable muscle AdN content can decrease to a larger extent than can be accounted for by known degradation products, suggesting that acid insoluble purine may be present (or formed) in skeletal muscle. To test this hypothesis, we first extracted tissue in perchloric acid/ethanol and then phenol extracted the acid insoluble material and performed anion exchange chromatography. Using extracts from rat liver (reported to be a rich source of the oligomer, Mowbray and Patel)) we isolated a fraction that was more anionic than ATP, and determined a phosphate to purine ratio of 3.8 and an ε_{max} at 260 nm. In skeletal muscle extracts, about 20% of the uv absorbing material eluted similarly, suggesting that ~0.2 to 0.4 µmol / g might be present in resting skeletal muscle. If this material interconverts with the soluble AdN pool it may explain AdN deficits found in ischemic, briefly contracting muscle (Tullson et al. *Am. J. Physiol.* 258:C258, 1990).

Supported by: NIH grant AR21617.

35.7

TIME COURSE OF AMP DEAMINASE ACTIVITY DECLINE IN RATS FED ß-GUANIDINOPROPIONATE. K.W. Rundell, R.L. Sabina, P.C. Tullson & R.L. Terjung. SUNY-Health Sci. Ctr, Syracuse, 13210; & Medical College.Wisc., Milwaukee, 53226

It has been demonstrated that AMP deaminase (AMPD) activity decreases to ~15% of normal in skeletal muscle of rats fed the creatine analogue ß-guanidinopropionic acid (ß-GPA) (personal communication, J.O. Holloszy). We verified the rapid onset (<2 wk) of reduced [ATP] and improved muscle performance (e.g., 3-fold greater sustained tension at 60 tetani/min) in adult male rats fed 1% ß-GPA. AMPD activity declined in an apparent 1st order manner to ~15% of initial. However, IMP production during 3 min of intense contractions (60 tetani/min) remained appreciable (~2.5 µmol/g) over the time course. There was no apparent change in transcript abundance of AMPD1 mRNA coincident with the precipitous decline in AMPD activity during the first 5 wks. ß-GPA remodeled muscle exhibits unique alterations in adenine nucleotide metabolism.



Supported by: NIH grant AR21617 and the MDA (RLS).

35.8

IMMOBILIZATION DECREASES mRNA CONCENTRATION OF TYPE I AND III COLLAGENS IN RAT SKELETAL MUSCLE. T.E.S. Takala*, X.Y. Han*, W. Wang*, P. Virtanen*, and R. Myllylä* (SPON: V. Kovanen). Department of Physiology, University of Oulu, Oulu, Finland and Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland.

Immobilization of rat hind limbs leads to a decrease in the enzyme activities of collagen biosynthesis in skeletal muscle (e.g. Savolainen et al. 1987). In the present study the concentrations of mRNAs for type I, III and IV collagens in soleus, plantaris and tibialis anterior muscles of cast immobilized rats were measured by hybridization of Northern and slot blots with procollagen-cDNA probes. Concentration of mRNA for type I and III collagens was already showed a decrease in tibialis anterior after 1 day of immobilization. The concentration of mRNAs for type I and III collagen were decreased in the all muscles studied after 3 days. The level of mRNA for type IV collagen dids not change significantly at any time point during the one week immobilization. These preliminary results suggest that immobilization reduces the expression of type I and III collagens, but not that of type IV collagen in rat muscles, and that adaptation of collagen biosynthesis is altered at the transcriptional level. Muscular activity seems thus be a positive regulator for the gene expression of the two collagen types which transmit muscle forces.

Reference: Savolainen, J., Väänänen, K., Vihko, V., Puranen , J., Takala, T.E.S. Am J. Physiol. 252: R883-R888, 1987

35.9

REGULATION OF MYOGENIC DIFFERENTIATION BY MATRIX MOLECULES. V. Kovanen, H. Larjava* and J. Heino*. Univ. of Jyväskylä, 40351 Jyväskylä and Univ. of Turku, 20520 Turku, Finland.

As transmembrane matrix receptors integrins are an important link between the force generating and the force transmitting compartments in skeletal muscle. In addition to binding cells to matrix integrins can also convoy signals into the cells, raising the possibility that they are involved in the regulation of myoblast behavior. The present study investigates (1) which integrins are expressed in the differentiating rat satellite cells in culture and (2) how type I collagen and laminin regulate the differentiation of these cells. The percentage of nuclei in myotubes was used as a fusion index and the activity of creatine kinase (CK) as a marker of muscle cell differentiation. The mRNA levels of myogenin, one of the master regulatory genes in myogenic differentiation, were analyzed by northern hybridization to see if they mediate regulation by the matrix components. The immunoprecipitation experiments showed clearly that at least $\alpha_3\beta_1$ integrins are expressed in the myotubes. Satellite cells plated on laminin showed a markedly higher fusion index and CK activity than those on collagen. However, myotubes had appeared earlier in cultures on collagen than on laminin, but they remained relatively small. Myotubes formed on laminin were large, striated and actively contracting. Myoblasts plated on laminin did not express myogenin mRNA, whereas differentiation into myotubes induced strong expression. Surprisingly, cells plated on collagen showed very early elevated myogenin levels which did not significantly increase thereafter. These results suggest (1) that $\alpha_3\beta_1$ may be one of the β_1 integrins in rat skeletal muscle cells and (2) that extracellular matrix regulates the expression of the myogenic differentiation, but at a level distinct from myogenin gene expression.

35.10

ENDURANCE TRAINING INDUCES DIFFERENTIAL EXPRESSION OF Na^+,K^+-ATPase SUBUNIT ISOFORMS IN RAT SKELETAL MUSCLE
Russell L. Moore* and Yuk-Chow Ng. College of Medicine, The Pennsylvania State University, Hershey, Pa

Endurance exercise training in animal models and in humans has been shown to attenuate the raise in plasma K^+ levels during exercise. In skeletal muscle, activity and number of the Na^+,K^+-ATPase (NKA), the functional unit of the Na pump, have been shown to be elevated in trained rats compared to controls. It has been postulated that the increased Na pump activity facilitates uptake of K^+ into the skeletal muscle and thus responsible for the attenuated raise in plasma K^+ level observed in trained subjects. NKA consists of a catalytic α subunit and a glycosylated β subunit. Three different isoforms of the α and β subunits are known. The effects of exercise training on the expression of the isoforms has not been studied. We, therefore, compared expression of α1, α2 and β1, three isoforms known to be expressed in rat skeletal muscle, in control and endurance trained rats. Female Sprague-Dawley rats were treadmill trained for 5-6 months. Crude membrane preparations were prepared from gastrocnemius muscle, and western blot analysis was performed using isoform-specific antibodies. In trained rats (T) the levels of α1 was reduced (T=1.22±0.19: C=1.97±0.12). β1 was greatly increased (T=4.42±0.26; C=2.67±0.42)($p<0.05$), and α2 remained unchanged (T=7.41±0.25; C=6.86±0.28) compared to control rats (C). These data indicate that in rat skeletal muscle endurance training causes isoform specific differential expression of the subunits. The increase in β1 may be responsible for elevated NKA activity observed previously. These results also demonstrate a possible physiological role of the β-subunit in regulating the Na pump activity. (Supported by NIH grants HL39723 and HL40306)

35.11

CHRONIC DYNAMIC EXERCISE DOES NOT ALTER PORCINE SKELETAL MUSCLE SIGNAL TRANSDUCTION. D. A. Roth, M. D. McKirnan*, R. Gelzer*, T. Hamilton*, H. B. Neuffer*, B. J. Smith*, C.M. Bloor, and H. K. Hammond.* VAMC-San Diego, and Depts. of Med. and Path., UCSD, La Jolla, CA 92093

We studied components of the β-adrenergic receptor (βAR)·G-protein·adenylyl cyclase (AC) transduction pathway in vastus lateralis (VL) and soleus (SOL) muscle from 6 endurance trained (ET) and 6 untrained (CON) pigs. ET pigs ran 5d/wk for 6 wks at 70% maximal heart rate. We have previously shown this regimen to elicit a 29% increase in VO_2 max and an 89% increase in biceps femoris citrate synthase activity. Maximal workload was increased (CON: 3.22±0.27; ET: 4.13± 0.30 Watts; $p<0.0003$), as was left ventricle/body weight ratio (CON: 2.6±0.2; ET: 4.0±0.8 g/kg; $p<0.009$), indicating training-induced myocardial hypertrophy. In biochemical studies, endurance training resulted in no significant change in lactate dehydrogenase activity in either SOL (CON: 167±56; ET: 144±39 µmol/g/min) or VL (CON: 490±85; ET: 454±127 µmol/g/min). Using ^{125}ICYP to identify βARs, we found no alteration in βAR number in either the SOL (CON: 23±7; ET: 23±6 fmol/mg), or VL (CON: 9±1; ET: 9±3 fmol/mg). Similarly, whether stimulated through the βAR, the stimulatory G-protein (Gs), or directly through the catalytic subunit of AC, cAMP production was not different in either muscle due to endurance training. Using specific antibodies for Gs and the inhibitory G-protein (Gi), immunoblots showed no significant change in either Gs or Gi in either SOL or VL due to endurance training. It is interesting to note that βAR number, cAMP production by all stimulants, and Gs content were 2-3 fold higher in the SOL as compared to the VL. We conclude that despite increased sympathetic tone due to daily running, neither of these metabolically diverse muscles appear to alter their βAR·G-protein·AC transduction pathway components, findings unlike those we have described in cardiac muscle.

35.12

CALPAIN-MEDIATED MYOFIBRILLAR PROTEIN DEGRADATION OF SIX-DAY TRACHEAL-BANDED HAMSTER DIAPHRAGM. S. Bryson*, W.D. Reid* and A.N. Belcastro*. (SPON: D.J. Sanderson). Schools of Human Kinetics and Rehabilitation Medicine, U.B.C., Vancouver, B.C., Canada, V6T 1Z1.

The purpose of this study was to assess the effects of resistive loading on protein degradation rates of individual myofibrillar-complexed proteins mediated by the Ca^{2+} activated neutral protease (calpain). Loading of the respiratory muscles was accomplished by placing a polyvinyl band around the trachea (TB). Six days later, an arterial blood sample from TB hamsters showed a severe respiratory acidosis and hypoxemia compared to controls ($p<0.05$). Myofibrillar protein yield, composition, sulphydryl group reactivity and calpain mediated degradation rates were compared. Although banding always resulted in lower yield of purified myofibrillar complexes from the diaphragm (TB= 54 ± 6; C= 59 ± 7 mg/g) ($p<0.05$), minimal differences existed between their electrophoretic (SDS-PAGE) protein profiles. Degradation rates of purified myofibrillar complexes (40 ug/ml) digested with calpain (1.5 U/ml) were faster for TB animals. For example, 55% of tropomyosin was degraded in 30 minutes compared to 8% in TB and controls ($p<0.05$). Sulphydryl group reactivities for the purified myofibrillar complexes were 167 ± 12 and 137 ± 13 nmol SH/mg/15 min, for control and TB ($p<0.05$). From the results of this study it may be concluded that resistive loading promotes myofibrillar protein degradation by increasing substrate selectivity to calpain, a nonlysosomal protease of skeletal muscle, which may be linked to the endogenous metabolic state. *Funding support from B.C.H.C.R.F. and N.S.E.R.C.*

35.13

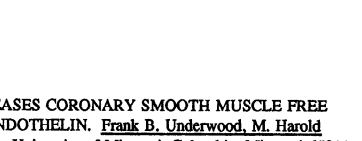
DOES CALPAIN MODIFY THE ACTIVITY OF SKELETAL MUSCLE CREATINE KINASE. G.D.Arthur* and A.N.Belcastro*. (SPON: D.J. Sanderson) School of Human Kinetics, U.B.C Vancouver, V6T1Z1, Canada.

The purpose of this study was to investigate whether the Calcium Activated Neutral Protease (Calpain) regulates the activity of Creatine Kinase (CK) prepared from skeletal muscle. The purity of our CK (EC.2.7.3.2.) preparation was assessed by SDS-PAGE, >88% was of the MM-isoform. CK activity was assayed using both ultraviolet and colorometric assays (Sigma). Calpain was purified from rabbit skeletal muscle using ion-exchange and hydrophobic chromatography. The specific activity was assayed using casein (2 mg/ml) as optimal substrate in 10mM DTT, 250mM Tris and 5mM $CaCl_2$ and expressed as OD280/mg/60 minutes. Calpain activity was typically between 5-6 U/ml. When the CK activity was assayed with a range of total calcium levels (0-50mM), the CK activity was reduced by 80% from 34.1 ± 0.4 to 7.2 ± 0.8 U/ml ($p<0.05$). Incubating CK with calpain (2 U/ml) removed the inhibitory effect of increasing Ca^{2+} concentration on CK activity. Using the colorometric assay the activities for CK, CK + 5mM Ca^{2+} and CK + 5mM Ca^{2+} + calpain were 43.6 ± 0.4, 16.4 ± 0.9 and 42.3 ± 0.7 U/ml, respectively. In contrast, the activity of calpain-treated CK, using the enzyme-coupled (hexokinase and glucose-6-phosphate dehydrogenase) UV assay method resulted in minimal (< 5%) recovery. This may be due to calpains action on these coupled enyzmes. The results suggest that CK activity in the presence of elevated calcium may be regulated by calpain. *Supported by N.S.E.R.C.*

35.14

EXERCISE TRAINING DECREASES CORONARY SMOOTH MUSCLE FREE CALCIUM RESPONSES TO ENDOTHELIN. Frank B. Underwood, M. Harold Laughlin, and Michael S. Sturek. University of Missouri, Columbia, Missouri 65211

Freshly dispersed coronary artery smooth muscle cells from exercise trained (TND) and sedentary control (SED) Yucatan miniature swine were exposed to porcine endothelin (ET-1, 5 x 10^{-8}M). Intracellular free calcium concentration ($[Ca^{2+}]_i$) at rest and during ET-1 exposure was determined using fura-2 microfluorometry and expressed as the fluorescence ratio. In physiological saline solution (PSS), the resting $[Ca^{2+}]_i$ in cells from TND animals was significantly higher ($p < 0.05$) than the $[Ca^{2+}]_i$ in cells from SED animals; however, the peak $[Ca^{2+}]_i$ in cells from TND animals after ET-1 exposure was only 76.5% that of the $[Ca^{2+}]_i$ in cells from SED animals, a significant attenuation (see figure). In a separate group of cells, the sarcoplasmic reticulum (SR) was filled with Ca^{2+} via depolarization with 80 mM potassium in PSS, then the cells recovered in PSS for two minutes. The ET-1-induced peak $[Ca^{2+}]_i$ was 18% lower in SMC from TND animals after SR filling, also a significant difference. These data support the hypothesis that exercise training alters coronary artery smooth muscle cell $[Ca^{2+}]_i$ responses to ET-1. (Supported by grants from the APTA to FBU, HL 36531 to MHL, and HL 41033 to MS).



35.15

THE REOXYGENATION/REPERFUSION OF HYPOXIC/ISCHEMIC SKELETAL MUSCLE INCREASES CYTOSOLIC CA^{2+} UPTAKE.

D.G. Welsh* T.W. Franklin* and M.I. Lindinger. School of Human Biology, University of Guelph, Guelph, Ontario, Canada N1G 2W1.

This study examined cytosolic Ca^{2+} uptake in the isolated perfused rat hindlimb during 5 min of normoxic stimulation ((stim) 1 Hz twitch at 15V) followed by either 40 min of hypoxic stim (PO_2 < 10 mmHg) and 20 min of reoxygenation stim (PO_2 > 120 mmHg) or in a second series; 40 min of ischemic stim and 20 min of reperfusion stim. Hindlimbs (n=24) were perfused at a flow of 1.5-2.0 ml·min^{-1} with an artificial plasma containing bovine erythrocytes, ^{51}Cr-EDTA as an extracellular fluid marker and $^{45}Ca^{2+}$. Using the paired-tracer isotope dilution technique, Ca^{2+} uptake was calculated from arterial and venous blood samples collected at 2.5-15 min intervals during the 85 min of perfusion. At rest and during 5 min of normoxic stimulation Ca^{2+} uptake was 2.88±1.14 and 2.41±1.02 umol·min^{-1}·g^{-1} perfused muscle (pm), respectively. Compared with normoxia, Ca^{2+} uptake during hypoxic stimulation did not change (0.77±2.83 to 4.16±3.95 umol·min^{-1}·g^{-1}pm). During reoxygenation/reperfusion, Ca^{2+} uptake increased approximately 10-fold and varied between 18.1±5.86-29.6±4.50 and 14.6±0.48-20.7±2.38 umol·min^{-1}·g^{-1}pm in the hypoxic/reoxygenation and ischemic/reperfusion model, respectively. This data supports the hypothesis that the reoxygenation/reperfusion of hypoxic/ischemic skeletal muscle alters Ca^{2+} homeostasis and induces cytosolic Ca^{2+} overload. Ca^{2+} overload is a characteristic feature of compromised cell viabilibility. Supported by NSERC of Canada

35.16

TECHNICAL CONSIDERATIONS FOR ASSESSING SKELETAL MUSCLE SARCOPLASMIC RETICULUM FUNCTION FOLLOWING EXERCISE.

Eva R. Chin, Fabienne Grange, James D. Mercer, Peter J. O'Brien and Howard J. Green. Univ. of Waterloo, Waterloo, Ontario, Canada N2L 3G1 and Univ. of Guelph, Guelph, Ontario, Canada N1G 2W1.

Conclusions regarding the effects of exercise on sarcoplasmic reticulum (SR) function may be influenced by methods of muscle tissue preparation. We have assessed the use of muscle homogenate (HOM) versus isolated SR vesicle (SRV) preparation and investigated the effects of freezing HOM and SRV on SR Ca^{++} ATPase activity and Ca^{++} uptake measurements. Muscle HOM and SRV samples were prepared from red (RG) and white (WG) gastrocnemius muscle of 12 female Wistar rats (weight = 290.7 ± 12.7, mean ± SE). Muscle HOM and SRV samples were analyzed immediately for maximum Ca^{++} ATPase activity and rate of active Ca^{++} uptake. Portions of each sample were quick frozen in liquid nitrogen and measurements repeated after storage at -80° C. SR membrane isolation resulted in a 20- and 17-fold purification of Ca^{++} ATPase activity and relative extraction of SR membrane was 14 and 11% in WG and RG, respectively. These values were similar for frozen samples. Quick freezing significantly reduced HOM basal ATPase (5.14 ± 0.2 to 4.06 ± 0.2 umole/min/g tissue ($p<0.05$)) but did not effect total or Ca^{++}-activated activity. HOM Ca^{++} uptake was reduced *by quick freezing* (12.7 ± 0.8 VS 10.2 ± 0.5 uM/sec). Quick freezing did not alter Ca^{++} ATPase activity or Ca^{++} uptake rates in SRV. *Differences* due to freezing were similar for both RG and WG. These results suggest that quick freezing alters HOM but not isolated SR vesicle permeability in rat skeletal muscle.

35.17

EFFECTS OF FATIGUE ON SARCOPLASMIC RETICULUM CALCIUM UPTAKE IN FEMALE CYCLISTS.

Dorabeth Parsons, Gretchen Tritchler*, Art Dickinson and Sherell Byrd. University of Colorado, Boulder, CO 80309.

Calcium uptake (Ca^{2+} uptake) by the sarcoplasmic reticulum(SR) is depressed after acute bouts of exercise in men or after exhaustive exercise in nonhuman animals (Gollnick, P. D.,1991, Byrd, S., 1989.) There are no reports of SR function in skeletal muscle during exhaustive exercise in women. The purpose of this study was to determine the pattern of Ca^{2+} uptake for moderately trained female cyclists during exercise to fatigue. The data were taken from eight active, average 60-80 miles per week, female cyclists, average age 28.0 ± 2.9 years, weight 59.05 ± 6.6 kg, VO_{2max} 50.2 ±1.54 ml/kg/min. The subjects were tested for VO_{2max} and rode one practice fatigue bout at about 75% of VO_{2max} to determine the onset of fatigue and the time schedule for muscle biopsies. Four biopsies were taken from the vastus lateralis muscle on a second fatigue bout; one at rest, two equally spaced about three quarters into to the bout and one biopsy at fatigue. Twenty ± 5.0mg muscle samples were homogenized, centrifuged and analyzed. The decreased rate of Ca^{2+} uptake was expressed as a percent change and decreased from 72.09 ± 6.07, to 52.93 ± 6.09, to 29.8 ± 4.57 % of resting values over a two to three hour period. This represents a 70% decrease in Ca^{2+} uptake at fatigue which is greater than that reported by Gollnick et al. (1991) for an acute bout of exercise, but similar to Byrd's (1989) data for exhaustive exercise. These data suggest that mechanisms of fatigue that alter SR function are related to work intensity and duration and are not gender or species specific.

35.18

ALTERATIONS IN SARCOPLASMIC RETICULUM Ca^{2+}-ATPase ACTIVITY IN HUMAN SKELETAL MUSCLE WITH PROLONGED EXERCISE.

H. Green, F. Grange*, E. Chin*, C. Goreham*, D. Ranney* and R.J. Xu*. Dept. of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1

To investigate the role of prolonged exercise on changes in skeletal muscle sarcoplasmic reticulum function, 7 untrained males ($\dot{V}O_2max$ = 44.4±6.6 ml·kg^{-1}·min^{-1}, $\bar{X}$±S.E.) cycled for 30 min at 58% $\dot{V}O_2max$ and until fatigue at 72 %$\dot{V}O_2max$. Measurements of maximal Ca^{2+}-Mg^{2+}-ATPase activity (total, basal) were performed spectrophotometrically at 25°C in the presence of the Ca^{2+} ionophore (A23187) on homogenates prepared from tissue extracted by biopsy from the vastus lateralis. Maximal Ca^{2+}-Mg^{2+} ATPase activity was depressed ($p<0.05$) by 15.9% at 30 min (5.04±0.26 μM·min^{-1} w.w.) and by 30.4% (4.17±0.24) compared to pre-exercise (5.99±0.20). Basal or Mg^{2+} ATPase activity was not different ($p>0.05$) between rest (1.04±0.09) and exercise at 30 min (0.94±0.06) or fatigue (0.91±0.05). Since basal activity was unchanged, the reduction in Ca^{2+}-ATPase activity with exercise paralleled the reduction in total Ca^{2+}-Mg^{2+} ATPase activity. It is concluded that sarcoplasmic reticulum function in humans is also altered by exercise in a manner consistent with what has been found in other species.

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35.19

MITOCHONDRIAL REORGANIZATION IN DIFFERENTIATING RAT L6 MUSCLE CELLS.

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Carbonic anhydrases (CA) are a multigene family of metalloisozymes that catalyze the intercorversion of CO_2 and HCO_3. They are found in almost all organisms, and the high activity forms are notable for their high turnover rates, ranking them among the most efficient enzymes known. The mitochondrian in many mammalian tissues contain an unique CA isozyme, CA V. In rat skeletal muscle CA V is located both in subsarcolemmal and interfibrillar mitochondrian. The physiological role of CA V in muscle tissue is unclear. In order to clarify the role of CA V we cultured rat L6 myoblasts in DMEM suplemented with 10 % fetal calf serum. The myoblasts were induced to differentiate by medium suplemented with 1 % horse serum and 4 IU/ml of insulin. The distribution of CA V was detected with a spesific antibody and rhodamine conjugated secondary antibody. Transmission electron microscopy was used to evaluate the distribution of mitochondria in myoblasts and myotubes. The CA V was noticed in the mitochondria of myoblasts (confirmed by rhodamine 123 staining). In myoblasts the mitochondria have a rod-like shape and are colocalized with tubulin. During differentiation large CA V positive mitochondria are localized at perinuclear zone. In multinucleated myotubes the mitochondria reorganize back to the rod-like shape and distribute evenly in the myotube. Using CA V as a mitochondrial marker we observed redistribution in L6 muscle cells. This reorganization seems to be related to the muscle cell differentiation. The expression of mitochondrial CA V protein is not however, related to the differentiation of L6 cells.

35.20

MITOCHONDRIAL ADAPTATIONS DURING CHRONIC MUSCLE USE AND DISUSE

David A. Hood, Mark Takahashi* and Karen Wicks*, Dept. of Physical Education, York University, Toronto, Canada.

The changes in mitochondrial components during chronic muscle use and disuse were used to study mechanisms regulating organelle synthesis and degradation, and the implications of these processes for endurance performance. Cardiolipin (CL) was used as a phospholipid marker, and cytochrome oxidase (CO) and succinate dehydrogenase (SDH) were measured as protein components of the respiratory chain in rat muscle following 10 Hz nerve stimulation (STIM) for up to 28 days (d), and denervation (DEN) for up to 42 d. Data were expressed per whole muscle mass to reflect tissue content, and corrected for water content. The increase in CL occured sooner ($t_{½}$= 4.2 d) than for SDH ($t_{½}$= 6.1 d) during the adaptation to STIM. Similarily, the decrease in CL ($t_{½}$= 4.1 d) during DEN preceded the decline in CO ($t_{½}$= 6.3 d). Changes in muscle CO and SDH activities were closely correlated ($r=0.86$, $p<.05$) with declines (DEN) or improvements (STIM) of muscle endurance performance measured during in situ contractions, relative to control muscle. The data indicate a higher turnover rate of phospholipid components compared to inner membrane proteins, and suggest that mitochondrial assembly and degradation are initiated by the insertion or removal of phospholipids.

(Support: NSERC, Canada).

36.1

MUSCLE-SPECIFIC LUCIFERASE EXPRESSION FROM RETROVIRAL VECTORS: TOOLS FOR GENE EXPRESSION REGULATION. Ji-wei Yang* and Donald B. Thomason. Univ. Tennessee Health Sci. Ctr., Memphis, TN 38163

We have developed three retroviral constructs that carry the chicken cardiac troponin T (cTnT129) promoter to drive the expression of firefly luciferase. The constructs also carry the Neo gene driven by the SV40 promoter for selection. We found the transient expression of luciferase ($\sqrt{CPM}$ / mg protein) is highly specific to muscle cells (2 times, $p<0.05$) when both L8 myogenic and NIH3T3 fibroblast cells were transfected with the same amount of vector without G418 selection. Given G418 (0.5 mg/ml) and awaited for the cells to be reconfluent, that difference was expanded to be as high as 12 times ($p<0.05$). Meanwhile we noticed when cTnT129-luciferase was in the reverse orientation from the 5'-LTR, the farther the muscle promoter, the higher the luciferase level ($p<0.05$). We anticipate these vectors will be packaged as retrovirus and therefore we can introduce the luciferase gene driven by cTnT129 promoter permanently either *in vitro* or *in vivo*. By use of these vectors, studies related to the regulation of muscle gene expression are possible. (Supported by NIH AR40901)

36.2

TRANSLATIONAL AND TRANSCRIPTIONAL MECHANISM OF AN ACTIVITY-INDUCED SHIFT IN SOLEUS MUSCLE POLYSOME PROFILE: . Donald B. Thomason and Zhu Ku*. Univ. of Tenn. Health Sci. Ctr., Memphis, TN, 38163.

A shift in apparent polysome size accompanies the downregulation of soleus muscle protein synthesis during non-weightbearing; we have observed that a similar shift for tenotomized soleus muscle. After only 5-18 h of treatment, polysomes from the soleus muscle shift toward apparently larger sizes on sucrose density gradients. The relative level of actin mRNA and 18S ribosomal subunits in each polysome band, as determined using cDNA probes, indicate the shift is a result of more 80S ribosomes per mRNA. The *in vivo* response mimics the *in vitro* response of L8 myogenic cells treated with low-levels of cycloheximide; this is consistent with the downregulation of protein synthesis through slowing of polypeptide elongation. Furthermore, in these models there is an apparent mobilization of RNA into the polysome pool, consistent with a feedback mechanism that could be similar to the *in vitro* cycloheximide-triggered protooncogene super-induction. Therefore, the activity-induced shift in polysome profile indicates a regulation of protein synthesis involving both translational and (post)transcriptional mechanisms. (Supported by NIH AR40901)

36.3

POTENTIATION OF *IN VITRO* CONCENTRIC AND ECCENTRIC WORK WITH MYOSIN LIGHT CHAIN PHOSPHORYLATION.
M.E. Houston* and R.W. Grange* (SPON: A.Bonen). Department of Kinesiology, University of Waterloo, Waterloo, Ontario, CANADA

Myosin light chain phosphorylation, a molecular mechanism temporally related to isometric twitch potentiation, was examined with respect to concentric (CW) and eccentric work (EW) potentiation using *in vitro* mouse extensor digitorum longus muscles at 25°C. Muscles were rhythmically cycled about Lo by a computer generated sine wave (7 Hz; 1.2 mm excursion) driving a Cambridge 300H servo arm. Contractions were induced by twitch-stimulation of optimal voltage. CW was evoked at 8 different phases between the maximum muscle length (L_{max}) and Lo (one stimulation per sine cycle). EW was induced at Lo during muscle lengthening. Both CW and EW were determined under non-phosphorylated (NP) and phosphorylated (P) (induced by a 20 s, 5 Hz train) conditions. In the NP state, CW was greatest at a phase just prior to L_{max} (1.62 ± 0.19 J x kg^{-1}) while EW was about 300% greater than this value. For the P versus NP states across all phases, CW was significantly potentiated $44 \pm 3\%$ ($n=4$; mean ± SEM; $p < 0.01$); however, EW was significantly potentiated only $20 \pm 4\%$. In contrast, isometric twitch potentiation under the same conditions is typically only 15 - 20 % at 25°C (Moore et al. 1990). CW but not EW potentiation was greater than isometric twitch potentiation. EW was greater than CW ($p < 0.01$) in both the NP and P states, likely due to stretching of series elastic elements. The smaller EW potentiation may be due to altered cross-bridge interactions during muscle lengthening.

Supported by NSERC Canada

36.4

VARIATION IN THE EXPRESSION OF CITRATE SYNTHASE mRNA IN HUMAN SKELETAL MUSCLE. J.A. Simoneau, Y. Gélinas*, R. Thériault*, G. Thériault, and F.T. Dionne*. Physical Activity Sciences Laboratory, Laval University, Ste-Foy, Québec, Canada, G1K 7P4.

The purpose of this study was to verify the cellular and molecular expression levels of citrate synthase (CS) in human skeletal muscle. Measurements of CS enzyme activity and of the CS mRNA content were performed in *vastus lateralis* muscle samples obtained from 20 physically active (PA) subjects, and from 24 sedentary (S) subjects before and after their knee extensor muscles were submitted to 6 weeks of low-frequency electrical stimulation (LFES). LFES was delivered at 8 Hz, 3 hrs/day, 6 days/wk, with the use of a portable stimulator and adhesive electrodes (Respond II and Pals Plus, Medtronic). More than a two-fold difference was observed in muscle CS activity as well as in CS mRNA content between PA subjects. The level of CS activity was significantly related to the CS mRNA content ($r=0.74$; $p<0.01$). On the other hand, ANOVA revealed that LFES induced significant increases in muscle CS activity (22%; $F=23.5$ $p<0.001$) and in CS mRNA content (18%; $F=5.6$ $p<0.05$), and these changes were similar in magnitude. Therefore, results of the present study indicate that variation in the CS mRNA content appears to be largely responsible for the cellular expression level of the human skeletal muscle CS enzyme activity.

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36.5

CONTINUOUS MOTOR NERVE STIMULATION RAPIDLY INDUCES EXPRESSION OF THE RNA SUBUNIT OF A MITOCHONDRIAL RNA PROCESSING ENZYME. George A. Ordway, Gregory A. Hand*, Kang Li* and R. Sanders Williams. UT Southwestern Medical Center, Dallas, TX 75235

Continuous motor nerve stimulation is a potent stimulus to mitochondrial biogenesis, which is accompanied by an increased DNA copy number. We have shown previously that this same stimulus markedly increases expression of the RNA subunit of an enzyme implicated in mitochondrial DNA replication, mitochondrial RNA processing (MRP) enzyme. To determine the time course of this increased expression of MRP-RNA relative to the induction of a mitochondrial respiratory enzyme, we electrically stimulated tibialis anterior muscles of rabbits for up to 21 days. Northern analysis showed MRP-RNA expression was increased after only 1 day of stimulation. Longer periods of stimulation further increased the abundance of MRP-RNA, which subsequently remained at levels approximately 20 fold greater than those seen in contralateral unstimulated muscles. By contrast, citrate synthase enzyme activity was not increased until 7 days of stimulation, after which activity increased 2.5-3.5 fold. These results demonstrate an important temporal relationship that further supports the potential regulatory role of MRP in mitochondrial DNA replication, and therefore oxidative phosphorylation, in skeletal muscle.

36.6

EVIDENCE THAT CARDIAC NA/CA EXCHANGER CONTENT MAY BE ALTERED WITH SENESCENCE AND EXERCISE TRAINING OF OLD RATS. Michael Hyek*, Calvin Hale, and Charlotte Tate. Dept. of Pharmacol., Univ. of Houston, TX; Dept. of Physiol., Univ. of Missouri, Columbus, MO.

Other investigators reported a lower activity of the cardiac Na/Ca exchanger in sarcolemmal vesicles isolated from old rats. To test the hypothesis that the content of the cardiac Na/Ca exchanger is lower in sedentary old rats and that *exercise training* results in an increased content of the exchanger, 24-mo. old Fischer 344 rats were divided into two groups, sedentary-old (SO) and exercised-old (EO), and were compared to 12-mo. old sedentary rats (SA). The content of the exchanger was estimated by immunoblotting techniques using the homogenate, and the EO rats ran for up to an hour/day, 5 d/week, for 8-10 weeks. Preliminary data indicated that the immunoreactive Na/Ca exchanger content was 40-50% lower ($p<0.01$) in the SO group compared to SA and EO groups. The data imply that a decreased content of the exchanger may be associated with aging and that exercise training may upregulate the protein. (Supported by NIH AG06221.)

43.1

PHYSIOLOGICAL STUDY OF SHAO LIN NUI JIN YI ZHI CHAN QIGONG. Masaaki SUGITA*, Youken JYO* and Kando KOBAYASHI*. (SPON: H. Hatta). Dept. of Sports Sciences, Univ. of Tokyo.

The purpose of this study was to investigate cardiovascular responses during qigong (Shao Lin Nui Jin Yi Zhi Chan) which is one of the methods in Chinese qigong. One male superior qigong instructor participated as a subject. Heart rates during primary grade static qigong were 121 bpm in average and 137 bpm at the maximum level. In the high grade static qigong heart rates were 94 bpm in average and 101 bpm at maximum. During spontaneous dynamic qigong heart rates fluctuated in the range of 80 to 160 bpm. Heart rate, ventilation and oxygen intake increased markedly after 35 minute of starting static qigong. It was observed that the finger movement style qigong contributed to the increase in heart rate and oxygen intake. Heart rate related to the certain oxygen intake tended to be higher during qigong than walking and running. The results of the present study suggested that the qigong subjected in the study has some influences to the autonomic nervous system even if the movement of qigong was not dynamic as walking and running.

43.2

MAXIMUM SUSTAINED METABOLIC LEVEL IN MICE EXPOSED TO ACUTE LONG-TERM COLD STRESS. Marek Konarzewski* and Jared Diamond. UCLA Medical School, Los Angeles, CA 90024-1751

Is there a ceiling on sustainable, time-averaged metabolic rate? If so, is that ceiling set by the gut's capacity to absorb nutrients? We studied these questions by exposing white mice to cold ambient temperatures for 2 weeks. The coldest temperature at which mice fed a high-sucrose diet could still maintain stable body mass was -10° C. Both intestinal mass and mass-specific brush border uptakes of glucose and proline increased, resulting in a 20% increase, compared to room-temperature values, in summed uptake capacity of the whole length of the small intestine for these nutrients. Digestive efficiency remained unchanged, while food intake increased 300% with the result that the excess of nutrient uptake capacity over nutrient intake declined to only a modest reserve capacity. Basal metabolic rate increased by 30% and heart and kidney size increased markedly. Therefore, an increased ability to assimilate food was coupled with parallel change in costs of maintenance of metabolic machinery. The increase in food intake of these mice at -10° C was comparable to the values found in mother mice at peak lactation. Thus, limits on food intake during cold exposure may limit the heat production and hence cold tolerance of mice.

43.3

CEILINGS ON ENERGY EXPENDITURE DURING LACTATION. Kimberly Hammond and Jared Diamond. UCLA, Los Angeles, CA. 90024.

By how much, if at all, does the intestine's capacity to absorb a nutrient exceed dietary intake of that nutrient in energetically demanding situations such as lactation, cold or exercise? Are limits on the intestine's absorptive capacity matched to limits in the ability of tissues like muscle and mammary glands to utilize the nutrient? We studied this question for glucose in mice. In virgin female mice, intestinal capacity to absorb glucose exceeds glucose intake by 200%. In mother mice at peak lactation (day 15), when food intake is 3 times higher than in virgin mice, the intestine hypertrophies by a lesser factor, so reserve capacity declines to less than 60% In addition, females with larger litters are evidently limited in their ability to supply their pups with nutrients, because pup mass at peak lactation declines over that in small litters. Because of the simultaneous declines in the intestine's reserve capacity and in pup mass, it is unclear if the limit resides in the intestine's capacity to transfer nutrients, the mammary gland's capacity to deliver milk, or both. We, therefore, performed two additional experiments. First, we experimentally extended the time mothers were required to supply all the nutrients to growing pups by 60% (to 24 days), to further increase the energy demand on the mothers. Second, we surgically reduced the number of working teats on mothers in order to determine if they could still raise the same number and size of pups. During extended lactation, reserve capacity of the small intestine diminished to near 0%, but pup size increased. When teat number was reduced by half, females could raise more than half the number of pups that they could with a normal teat number, but pup mass was slightly smaller than normal. These data suggest that there are simultaneous limits on both intestinal absorptive capacity and mammary secretory capacity.

43.4

MECHANICAL EFFICIENCY IN WOMEN WITH DIFFERENT BODY FAT DISTRIBUTION PATTERNS. P.D. Swan, Univ. of Colorado, Boulder, CO, 80309 and E.T. Howley, Univ. of Tennessee, Knoxville, TN 37916

It has been hypothesized that body fat distribution affects energy expenditure (mechanical efficiency) during exercise. To test this hypothesis pre-menopausal obese (% Fat > 30%) women, characterized by waist to hip (WHR) ratios into upper body (UP; WHR $\geq$ 0.85) and lower body (LB; WHR $\leq$ 0.75) groups (N = 10 each), volunteered to participate. Subjects completed four 6-minute steady state tests for weight supported (cycle) and weight carrying (treadmill) exercise, with gas exchange measured at 4-6 minutes into each test. Work rate on both the cycle and treadmill were closely controlled. Mechanical efficiency (ME) values were based on the ratio of work accomplished to energy expended. Gross and net efficiency were not different between groups for either mode of exercise (i.e., cycling gross ME range 17-20% & walking gross ME range = 10-19%). In conclusion, there is no support for the notion that exercise is less useful for LB obese subjects in a weight reduction program. Obese women with different body fat patterns have similar potentials for energy expenditure during exercise.

43.5

EXERCISE AGAINST SELF-GENERATED LOWER BODY NEGATIVE PRESSURE. DE Watenpaugh*, RE Ballard*, GA Breit*, and AR Hargens. Life Science Division (239-11), NASA Ames Research Center, Moffett Field, CA 94035-1000

Exercise against the footward force produced by lower body negative pressure (LBNP) may provide a simple and inexpensive technique to simulate gravity during spaceflight. To allow the legs themselves to generate the negative pressure against which they work, a flexible cylinder around the lower body and sealed at the waist expands and collapses longitudinally, but not radially. As the legs push footward to expand the cylinder, the air pressure in the cylinder decreases, increasing the force required to continue expanding the cylinder. The negative pressure is limited by an adjustable valve to allow controlled air flow into the cylinder. An additional valve remains shut during cylinder expansion, but allows air to enter the cylinder during retraction. Shoulder straps and handles on top of the cylinder allow the user to counteract the downward force exerted by their legs. Force produced depends on air inflow rate, cylinder radius, and length and rate of expansion. In four supine healthy male subjects (weight: 75.5 ± 5.2 kg, X ± se), knee bend exercise (analogous to repetitive concentric leg press) was performed at 19 cycles/min for 5 to 6 min. Footward force was measured with load cells, cylinder pressure with a transducer, heart rate from ECG, and oxygen consumption with turbine volumetry and gas analysis. Maximum footward force at the peak of the exercise cycle averaged 1168 ± 108 N (119 ± 11 kg), and pressure within the cylinder concomitantly decreased 22 ± 3 mm Hg below ambient. Heart rate and oxygen consumption increased 71 ± 4 beats/min and 25.0 ± 0.7 ml O_2/kg/min from supine resting values, respectively. With the adjustable valve nearly closed, exercise with this device is analogous to a leg press. With more inflow of air, more rapid knee bends can be performed. Workload increases with increasing leg mechanical advantage during exercise with this device. Modifications are planned to permit eccentric as well as concentric exercise. This exercise device/concept provides simultaneous dynamic musculoskeletal and cardiovascular stresses without an external power source. (Supported by NASA Grant 199-14-12-04)

43.6

LOW FREQUENCY SOUND DURING EXERCISE TESTING: IMPACT UPON AUSCULTATORY BLOOD PRESSURE MEASUREMENTS. J. T. Lightfoot and T.S. McCain*, Florida Atlantic University, Boca Raton, FL 33431

Recent articles have questioned the validity of auscultatory blood pressure measurements due to the increase in ambient sound levels during exercise, especially diastolic pressures (DBP). However, there is no data documenting the low frequency sound pressure spectrum during exercise. Using a sound pressure level (SPL) meter and signal analyzer, the low frequency sound pressure spectrum (0-100 Hz; SPL in dBA, ref=20μ Pa) was measured both ambiently and in a stethoscope tube during several exercise conditions. With the treadmill set at 94 m/min, phase IV DBP (30 dBA@50Hz) was masked both with (45 dBA@50Hz) and without (39 dBA@50Hz) a subject walking on the treadmill. Similar sound levels were observed with a 51 kg subject (45 dBA@50Hz) and a 109 kg subject (41 dBA@50Hz). During exercise on a cycle ergometer, ambient SPL increased with an increase in rpm from 50 (37 dBA@50Hz) to 90 rpm (47 dBA@50Hz) (resistance = 1.5 kp). Even though the use of a stethoscope during blood pressure cuff deflation decreased ambient sound interference, DBP was still masked during treadmill (94 m/min) and cycle (75 W) exercise (38 and 28 dBA@50Hz, respectively). Systolic blood pressure was not obscured in any condition. These data suggest that sound generated during exercise testing may impair the validity of auscultatory DBP measurements.

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43.7

ARM STRENGTH IS A DETERMINING FACTOR IN ROWING EXERCISE. R.L. Jensen and C. F. Fromme. Dept. KHPR, Univ. of North Texas, Denton, TX 76203

The relationship between oxygen uptake, power output (PO), and maximal blood lactate (MBL) during rowing and measures of arm and leg strength was investigated in active, but untrained subjects (n=12). Arm flexion strength (ARM) and leg extension strength (LEG) were the peak torque of five reps measured with a Hydra-Fitness Omnitron. Combined strength (COMB) was the sum of arm and leg strength. Peak oxygen uptake, expressed in absolute (ABS) and relative to body mass values (REL), PO, and MBL were obtained during rowing exercise on a Concept II ergometer. Stepwise regression using a bootstrap analysis of 20 random samples (ten subjects per sample selected from the total group of 12) indicated that ARM predicted MBL (R=.59 to .75), REL (R=.60 to .83), and PO (R=.65 to .88). Prediction of ABS was possible using COMB (R=.61 to .74). In conclusion, data from the current study indicate that strength, in particular arm strength, is an important factor in the attainment of peak oxygen uptake, blood lactate, and power output during maximal rowing exercise.

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MACROCIRCULATORY PHYSIOLOGY

44.1

HEMODYNAMIC ADAPTATIONS TO ENDURANCE TRAINING: LINKS TO CARDIOVASCULAR STRUCTURE. G.K. Savard, P. McDonald, A.J. Sanfilippo and H. Wang. Queen's University, Kingston, Ontario, Canada, K7L 3N6.

The link between the cardiovascular adaptations to chronic exercise training and cardiovascular structure was investigated. The lowering of mean arterial pressure and heart rate with 10 wks of moderate endurance training in young men occurred in the absence of any significant changes in carotid-cardiac baroreflex function (barocuff method) and cardiac structure (echocardiography), although spontaneous baroreflex function (gain of beat-by-beat changes in heart period with SBP) and left ventricular filling velocity improved. A hemodynamic assessment of vascular structure by plethysmography indicated that the average lumen size of limb vasculature increased with training. Thus, training-induced decreases in MAP and HR in normotensive men can occur in conjunction with changes in baroreflex function and cardiac filling dynamics in the physiological range of blood pressure, as well as with adaptations in vascular but not cardiac structure.

Supported by NSERC.

44.2

CARDIOVASCULAR RESPONSES WITH RAPID ALTERNATE EXPOSURE TO SIMULATED 0 AND +2 G_z. M.E. Tschakovsky* and R.L. Hughson. Dept. of Kinesiology, Univ. of Waterloo, Waterloo, Ont. N2L 3G1.

We have studied a ground based analog of parabolic flight to evaluate the ability of several non-invasive cardiovascular methods to follow the dynamic responses. Four subjects completed 1 h 17 min at 30° head up tilt (HUT), control and 30 min at 30° HUT followed by 40 repeated 30 s alternate exposures at -5° head down tilt (HDT) (simulated 0 G_z) and 70° HUT plus -40 mmHg lower body negative pressure (LBNP) (simulated +2 G_z). Heart rate was measured along with impedance cardiography estimates of stroke volume (SV) and cardiac output ($\dot{Q}$). Mean arterial blood pressure (MAP) was monitored non-invasively by Finapres (Ohmeda Inc.). Data are means ± SD.

	HR (b/min)		SV (ml)		CO (L/min)		MAP (mmHg)		TPR (mmHg/L/min)	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Control	67.1 ±15.1	67.6 ±17.5	84.1 ±20.4	86.9 ±28.6	5.5 ±0.8	5.5 ±0.9	73.0 ±6.1	77.2 ±8.0	13.6 ±1.8	14.2 ±2.4
Sim. 0 G_z	58.7† ±4.4	54.1†* ±5.6	109.7† ±17.4	122.7† ±26.2	6.4† ±1.0	6.6† ±1.6	78.0 ±8.7	87.5# ±4.3	12.6 ±2.2	13.8 ±3.0
Sim. +2 G_z	97.4†* ±11.4	103.5†* ±20.6	46.6†* ±6.7	46.5† ±10.2	4.5† ±0.2	4.6† ±0.2	82.2 ±11.7	92.0*# ±10.0	18.8†* ±2.4	20.1†* ±2.5

†significant difference from control (*), between 0 G_z and +2 G_z ($), from early (#). All at p < 0.05.

We previously demonstrated that changes in HR, SV, CO and TPR during 4 h continuous HDT were transient, and that MAP did not change. In this study MAP increased ($p < 0.05$) over time in the 0 G_z and +2 G_z conditions. HR, SV, CO and TPR remained different ($p < 0.05$) between 0 G_z and +2 G_z and showed no signs of returning to control levels throughout. Unlike continuous microgravity, simulated parabolic flight does not result in gradual normalization of cardiovascular variables in the 0 G_z condition.

44.3

REGULATION OF CARDIAC OUTPUT DURING CHRONIC VASOCONSTRICTION. J-P. Montani*, R.L. Summers* and T.H. Adair. Dept. Physiology, Univ. Miss. Med. Ctr, Jackson, MS.

The main objective of this study was to determine whether whole body blood flow autoregulation can be maintained during long-term administration of a potent vasoconstrictor. We infused phenylephrine (1 μg/kg/min i.v.) for 10 days (d1-d10) in 5 dogs. Phenylephrine (PE) caused an immediate increase in mean arterial pressure (MAP, mmHg), a sustained decrease in cardiac output (CO, l/min) and heart rate (HR, b/min), and a marked increase in total peripheral resistance (TPR, mmHg/l/min), as shown in the Table.

	MAP	CO	TPR	HR
Control	90 ± 5	2.33 ± .11	40 ± 3	68 ± 4
PE,d1	116 ± 11	1.77 ± .07	68 ± 6	52 ± 3
PE,d3-5	*102 ± 6*	1.71 ± .10	64 ± 6	51 ± 3
PE,d8-10	101 ± 6	1.76 ± .11	61 ± 7	53 ± 3
Post,d1	81 ± 2	2.15 ± .18	39 ± 4	100 ± 8
Post,d5-8	83 ± 1	2.30 ± .19	38 ± 3	73 ± 3

Hematocrit (Hct) increased from a control value of 38±3% to 57±4% on d1 of PE and remained elevated throughout the infusion (Hct = 53±4% on d10). These data show that PE can produce a sustained vasoconstriction with a chronic decrease in CO. However, oxygen delivery to the tissues was probably well maintained since the product of CO and Hct did not change significantly during the period of PE infusion. (Supported by NIH HL-11678 and MS-90-G-15).

44.4

THEORETICAL ANALYSIS OF THE PERIPHERAL FACTORS WHICH DETERMINE CARDIAC OUTPUT DURING EXERCISE. **Sheldon Magder and Catherine Notarius. Division of Critical Care and Meakins-Christie Laboratories, Royal Victoria Hospital, McGill University, Montreal, Canada H3A 1A1.**

This analysis is based on the premise that cardiac output must equal venous return and that the heart can only increase venous return by lowering right atrial pressure (**Pra**). Since **Pra** usually does not change, or increases during exercise, the increase in cardiac output must be due to a change in the factors which determine venous return. Caldini et al (Circ. Res. 1974) developed a model for venous return which is described by $VR = v - Pra\ Ct/(Ff\ Rf\ Cf + Fs\ Rs\ Cs)$. **f** and **s** refer to fast and slow time constant beds and have been shown to relate to the peripheral and splanchnic circulations respectively. **v** = stressed volume or total minus unstressed (**Vo**) volume; **Ct** = total venous compliance; **F** = distribution of flow to fast and slow beds; **R** and **C** = venous resistance and compliances. We substituted experimentally derived results from resting dogs into this equation and applied the model to a 70 kg man. **VR** at **Pra** = 0 (VR_{max}) was set at 5.5 l/min and **v** at 25% of a total blood volume of 5.5 l; **Fs** = .45, **Ff** = .55, **Rs** = .20 mmHg/ml/sec, **Rf** = 0.143, **Cs** = 119 ml/mmHg and **Cf** = 28. The mean systemic pressure (**Pms**) = 8 mmHg. If 90% of blood flow goes to the muscle, VR_{max} would increase to 10.6 l/min with no change in **Pms**. An increase in **v** by 10 ml/kg as we have observed during baroreceptor hypotension, would increase VR_{max} to 8.7 l/min and **Pms** to 12.8 mmHg. A change in distribution and **v** would increase cardiac output to 18.8 l/min. A 50% decrease in **Rs**, as occurred during baroreceptor hypotension, would increase the cardiac output to 9.3 l/min. A 50% decrease in **Cs**, as might occur with an "abdominal" pump would increase VR_{max} to 9.3 l/min and **Pms** to 13.5. A 50% decrease in **Cf** and **Rf** from muscle contractions would increase VR_{max} to 6 l/min. A combination of all the above would increase cardiac output to 23 l/min.

44.5

APPROACHES TO VENTRICULAR EJECTION FRACTION AT REST AND EXERCISE BY USE OF MYOCARDIAL RADIOTRACERS. Richard P. Spencer, John A. Vento.* Univ. Connecticut Health Center, Farmington, CT 06030 & VA Medical Center, Newington, CT.

Radionuclide evaluation of cardiac ejection fraction (EF) is usually accomplished by means of labelled red blood cells (RBC) and gated ECG acquisition. Since the majority of cardiac studies in Nuclear Medicine now utilize myocardial-avid agents, rather than those localizing in the blood pool, we examined use of the heart wall agents for EF measurements. 1) As the radioactive bolus traverses the ventricles, the "first pass" method can be employed, but high count rates may introduce "dead time" errors. 2) The EF can be calculated from end systole and end diastole images, making a reasonable assumption about the geometry of the ventricular cavity (such as an ellipsoid of revolution). This is a variation of the classical radiographic approach. 3) We attempted to utilize: Cardiac volume (total) = wall mass + blood pool, by examining the external borders of the heart. However, this encountered multiple problems likely related to: uneven contractility of the muscle as well as spatial resolution. The topic however is a reasonable one for further study. Hence, EF can be measured by use of myocardial-avid agents with first pass or geometric techniques, but in depth analysis is required concerning volume changes as measured by alterations in external cardiac size.

44.6

SPLENIC RESPONSE TO MEDICATIONS: COULD THIS BE AN "EXERCISE EQUIVALENT?" John A. Vento*, Richard P. Spencer, Fazle Hosain. University of Connecticut Health Center, Farmington, CT 06030 and V.A. Medical Center, Newington, CT 06111.

Defining the anaerobic threshold can be invasive and time consuming. The response of individual organ systems to exercise or to a "pharmacologic equivalent" might provide a simple or parallel approach. We analyzed data concerning the splenic blood pool and its response to exercise or medication. A frequent clinical study is estimation of cardiac function by quantitification of the ventricular filling and emptying of labeled RBC (Tc-99m-RBC). These cells can also be utilized to evaluate splenic content before and after medications or exercise. I) Visualizing the splenic labeled RBC's before exercise and then as soon as possible afterward in 25 cases showed a decreased number of occupied pixels (76%), decrease in total counts over the spleen in 84%, decreased counts/pixel in 88% and decrease in 1 or more measurements in 92%. Further studies are needed to determine if the decline onset matches the point of anaerobic threshold. II) The spleen also responds to administered epinephrine (EP) and nor-EP. It may be feasible to calculate a "medication equivalent" for a given amount of exercise.An analogy might be the response of a tumor to either chemotherapy or radiation. Hence, calculation of "exercise equivalent" appears feasible for the spleen, via utilization of radiolabeled RBC.The method might be extended to other internal organs as well.

44.7

RESPIRATORY-SYNCHRONOUS FLUCTUATIONS IN VASCULAR RESISTANCES IN UNANESTHETIZED DOGS Kurt W. Saupe, Curtis A. Smith, Kathleen S. Henderson and Jerome A. Dempsey. Dept. of Preventive Medicine, University of Wisconsin, Madison, WI 53705

We sought to determine, 1) if the respiratory synchronous discharge pattern of sympathetic nerves causes respiratory synchronous fluctuations in vascular resistances (RSFVR) and 2) the role of pulmonary stretch receptors (PSRs) and arterial baroreceptors in causing any RSFVR. Three female dogs chronically instrumented with ultrasonic blood flow probes (external iliac, celiac, and renal arteries), respiratory muscle EMGs, tracheostomies, and an exteriorized carotid artery were studied while resting quietly in lateral recumbency. Vascular resistances were calculated beat-by-beat in the 3 arteries by dividing systolic blood pressure by systolic blood flow. In each dog, all 3 regional vascular resistances fluctuated in synchrony with breathing, increasing during inspiration and falling during expiration. Fluctuations ranged from a doubling of external iliac resistance during sighs, to 15-20% swings in the celiac artery during eupnea. We found that the RSFVR continued unaltered during periods when BP did not fluctuate, eliminating baroreceptors as a possible cause. During isocapnic mechanical ventilation with large tidal volumes (loss of central respiratory drive and an increased PSR stimulation) the RSFVRs not only failed to increase in size but were greatly attenuated. We conclude that: 1) vascular resistances fluctuate in synchrony with breathing, 2) these fluctuations are not caused by breathing-related activation of cardiopulmonary reflexes, 3) the RSFVR likely result from a direct effect of inspiratory drive on vasomotor activity. (Supported by NHLBI)

44.8

VARIABLE BALANCE BETWEEN α- AND ß-ADRENERGIC EFFECTS ON LOCAL VASCULAR RESISTANCE IN WORKING MUSCLE IN MAN. Ole M. Sejersted, Jostein Hallén* and Lars Gullestad*. National Inst. of Occupational Health, N-0033 Oslo, Norway.

The contribution of ß-adrenergic stimulation to vasodilation in muscle might depend on the noradrenaline (NA) spillover which is closely related to exercise intensity. Experiments were performed before and during ß-adrenergic blockade with propranolol (0.15 mg/kg) after catheters were inserted into the femoral vein and artery. Six healthy women performed continuous bicycling with 5 powersteps of 30-40 W lasting 4 min each. Leg blood flow (LBF) was determined by bolus injections of indocyanine green. LBF was reduced with propranolol at low power output (37 W: 1.8±0.2 vs 2.3±0.2 l/min, $p<0.05$), due to increased local vascular resistance (LVR) (55±5 vs 46±4 mmHg·min/l, $p<0.05$), since the blood pressure (BP) was not significantly lowered. During maximal power LBF, LVR and BP were not significantly changed during propranolol (200W: 4.5±0.3 vs 4.5±0.5 l/min, 24±2 vs 23±2 mmHg·min/l, 119±11 vs 115±8 mmHg respectively). Plasma NA was 42.2 nmol/l compared with 1.8 nmol/l at rest. We conclude that ß-adrenergic receptors mediate local vasodilation in muscle, but that this effect is insignificant when sympathetic nerve discharge is high at high exercise intensities.

44.9

ZABICIPRIL INCREASES COLLATERAL BLOOD FLOW DURING EXERCISE IN RATS WITH ACUTE FEMORAL ARTERY LIGATION. H.T. Yang & R.L. Terjung. SUNY-Health Science Center, Syracuse, NY 13210

To evaluate the effect of angiotensin-converting enzyme (ACE) inhibition on collateral dependent blood flow (BF) during exercise, adult male Sprague-Dawley rats were fed Zabicipril at 0, 0.3 and 3.0 mg/kg/d (n=12/group) for 6 days. Under ketamine-acepromazine anesthesia, the carotid and caudal arteries were catheterized for BF determination and both femoral arteries were ligated to remove the primary route for BF to the distal limb tissue. Following recovery from surgery (~4 hr), collateral-dependent hindlimb BF was determined at two treadmill speeds (15 and 25 m/min at 15% grade) with ^{85}Sr and ^{141}Ce labeled 15μ microspheres. Zabicipril ingestion did not affect body weight or blood pressure and heart rate during exercise. However, BFs to the total hindlimb, as well as the distal limb tissue (including the gastrocnemius-soleus-plantaris muscles) were ~45% higher at 15 m/min in Zabicipril treated group ($P<0.025$). Further, raising the speed to 25 m/min failed to improve BF; therefore, maximal BFs were likely achieved. We interpret these results to indicate that ACE inhibition serves to lower resistance of collateral vessels. This implies that local factors modify collateral resistance and lead to increased BF to collateral-dependent distal limb tissue following acute onset ischemia.

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44.10

APPLICATION OF VENOUS OCCLUSION PLETHYSMOGRAPHY TO THE THIGH. D. Proctor, D. Bredle, J. Roemmich, W. Sinning. Kent State University, Kent, OH 44242.

Few studies have used venous occlusion plethysmography to estimate thigh blood flow (Q_{Th}), even though it is important because the thigh contains the major muscles for many aerobic activities. The present study determined the reliability of this method with supine cycling. Ten males (30±3y, 76.7Kg) completed a discontinuous, incremental cycling test (4 min exercise, 10 min rest) to maximum on two days (D1, D2). Q_{Th} (ml/100ml/min) was measured at rest and 30 seconds following each work rate. Q_{Th} reached a plateau at 176.5 W, possibly due to venous congestion at higher work rates. Also, Q_{Th} averaged 16% higher ($P=0.04$) on D2. Consequently, the responses of Q_{Th} were regressed against VO_2 and tested for equality of slope, excluding values for work rates above 176.5 W. No significant difference was found between the slopes on D1 and D2 ($P=0.85$). It was concluded that proportional changes in submaximal Q_{Th} are similar for different days, even though absolute Q_{Th} values may differ. Between test differences suggest some form of habituation to the procedure.

45.1

TRANSIENT INCREASES IN CAPILLARY HYDRAULIC CONDUCTIVITY (Lp): A NEW ROLE FOR ADENOSINE RELEASE DURING EXERCISE. D. A. Williams and V. H. Huxley. Dept. of Physiology, U. Missouri, Columbia, MO 65212

Recent evidence has suggested that vasodilators increase permeability of capillaries to water (Meyers & Huxley, Circ. Res. 70: 1992). Thus, we hypothesized that adenosine (ADO), a potent vasodilator released during exercise, would elevate capillary Lp. Mesenteries of pithed frogs (*rana pipiens*; n=10) were exteriorized and superfused with frog Ringer's solution (14-16°C). Single vessels, identified according to flow criteria as arteriolar- (AC), true- (TC), or venular- (VC) capillaries, were cannulated with micropipettes and perfused at pressures (ΔP) between 15-40 cm H_2O. Using human red blood cells as flow markers, Lp was measured according to the modified Landis technique during perfusion with control (Lp^C; 10 mg·ml^{-1} bovine serum albumin (BSA) in frog Ringer's) or test (Lp^T; 10^{-5} or 10^{-4} M ADO, 10 mg·ml^{-1} BSA, and frog Ringer's) solutions. Lp was calculated as the slope of ΔP versus water flux per unit surface area. In general, capillary Lp responses to ADO differed according to network location. AC (n=4) were less leaky to water upon exposure to ADO compared to control (Lp^T/Lp^C = 0.8 ± 0.3, mean ± SE). For TC (n=5), the early (0-2 min) Lp response was 3.5 ± 1.2-fold higher than control and then Lp of TC returned quickly to control levels ($Lp^{2\text{-}20\ min}/Lp^C$ = 1.7 ± 0.8). Average Lp response to ADO in VC (n = 2) did not change. These data are consistent with vasodilators increasing capillary Lp and indicate that, during the initial, transient phase of exercise, water movement into interstitial and tissue spaces may be facilitated by adenosine. NIH HL07094 & HL42528; VHH is an AHA EI.

45.2

CAPILLARY GROWTH FOLLOWING SKELETAL MUSCLE FIBER HYPERTROPHY. Gregory K. Snyder. Department of Biology, University of Colorado, Boulder CO 80309-0334.

We determined the effects of fiber hypertrophy, from weight-loading, on selected enzymes and on capillary growth in chick m. anterior latissimus dorsi. Muscles were removed from chicks and quick frozen in isopentane cooled with liquid nitrogen. Transverse sections of the frozen muscle blocks were cut on a cryostat and collected on cover slips. Capillaries and muscle fibers of the sections were visualized histochemically with the ATPase method. Other blocks were homogenized and processed for citrate synthase (CS) activity or lactate dehydrogenase (LDH) activity.

Weight-loading increased muscle mass and muscle fiber area an average two-fold over controls. LDH, an enzyme marker for anaerobic metabolism, was not correlated with normal growth or with hypertrophy. CS, an enzyme marker for aerobic metabolism, was inversely correlated with normal growth, but not with hypertrophy. The number of capillaries per muscle fiber, the only true index of capillary growth, increased with muscle fiber size, but, capillary density decreased with increased fiber size. When corrected for differences in fiber size we found no significant effect of hypertrophy on capillary growth; e.g., all of the capillary growth can be attributed to fiber growth and not to increased work load *per se*. The data show that there is a constant muscle fiber surface area served per capillary. We suggest that capillary growth is regulated by a parameter keyed to the average distance between capillaries around the fiber perimeter.

Supported by NIH RO1-HL32894 and NSF DCB8818647.

45.3

SARCOMERE SPACING AND CAPILLARY GEOMETRY CHANGE RECIPROCALLY FOR RAT SOLEUS AND EXTENSOR DIGITORUM LONGUS MUSCLES IN VIVO M.A. Ledvina* and S.S. Segal. Noll Laboratory, Pennsylvania State University, University Park, PA 16802

We evaluated passive changes in muscle (Lm), fiber (Lf) and sarcomere (Ls) lengths and capillary geometry in the parallel-fibered soleus (SOL; slow-twitch) and extensor digitorum longus (EDL; fast twitch) muscles throughout their anatomical range of motion. Female rats (n=9, 243±2g) were anesthetized (pentobarbital, 35 mg·kg^{-1}) and the antagonistic SOL and EDL exposed, irrigated with physiological saline solution (34°C; pH,7.4), and studied with intravital video microscopy. As foot angle increased from 30 to 170°, Lm and Ls (mean±SE) increased ($p<0.05$) for EDL (27.5±0.4 to 31.0±0.3 mm and 2.3±0.01 to 3.1±0.05 μm, respectively) and decreased ($p<0.05$) for SOL (26.1±0.4 to 20.3±0.3 mm and 3.2±0.03 to 2.2±0.04 μm). Lf changed in parallel with Lm and Ls within each muscle but varied for posterior, anterior, and lateral surfaces in both muscles. The ranges of respective length changes were greater ($p<0.05$) in SOL vs. EDL. Capillary tortuosity decreased with increasing Lm, Lf, and Ls in both muscles and was greater ($p<0.05$) in SOL at each corresponding length. We conclude that capillary geometry is directly influenced by muscle, fiber, and sarcomere length in vivo but this effect is not uniform between muscles of similar fiber architecture yet different fiber types.

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45.4

EFFECTS OF CHRONIC HIGH-INTENSITY ENDURANCE TRAINING ON SKELETAL MUSCLE MICROCIRCULATION. D.C. Gute*, C.H. Fraga*, J.F. Amann*, and M.H. Laughlin. Col. of Vet. Med., Univ. of Missouri, MO 65211.

Capillarization of several rat hindlimb muscles was evaluated among sedentary (C) rats and rats exposed to a high-intensity endurance training protocol (H) which consisted of running on a motor driven treadmill 5 days per week for 1.5 hours per day up a 15% incline at 32 m/min for 12-16 weeks. After completion of training rat hindquarters were surgically isolated, maximally vasodilated with papaverine (1 mg/10 ml perfusate), and perfused with Tyrode's solution with 5% BSA added until isogravimetric flow was established. Hindquarters were perfusion fixed with modified Karnovsky's fixative. Capillary and muscle cell fiber morphometric parameters were measured on histologic sections of the individual muscles utilizing the Olympus Cue 2 Image Analysis System. Average fiber area (FA), capillary numerical density (CND), and capillary/fiber ratio (C/F) were calculated. Muscles studied included soleus (S) (primarily type I fibers) and the red, mixed, and white portions of the gastrocnemius muscle (Gr, Gm, and Gw respectively). The latter three portions of the gastrocnemius represent a decreasing percentage of type IIA muscle fibers. Calculated average fiber area was increased in Gr and S with no changes seen in Gw and Gm. CND and C/F ratio were increased in all portions of the gastrocnemius. CND appeared to be increased in the soleus muscle.

	GRP	n	Gw	n	Gm	n	Gr	n	S
FA	C	(2)	2794±114	(5)	2249±47	(4)	2007±62	(5)	2430±56
	H	(5)	2875±82	(5)	2177±117	(5)	1659±69	(5)	2122±81
C/F	C	(2)	1.54±.08	(5)	2.61±.11	(4)	3.07±.10	(5)	3.73±.15
	H	(5)	2.32±.09	(5)	3.53±.14	(5)	3.36±.08	(5)	3.84±.09
CND	C	(2)	558±34	(5)	1177±53	(4)	1563±58	(5)	1537±41
	H	(5)	836±43	(5)	1697±79	(5)	2060±70	(5)	1865±70

We conclude that high-intensity endurance training appears to increase skeletal muscle capillarization. Supported by NIH Grant #HL 36088.

45.5

EFFECT OF ACUTE AND CHRONIC ACTIVITY ON MICROCIRCULATION IN SKELETAL MUSCLE O. Hudlicka, Department of Physiology, University of Birmingham, B15 2TT, UK

Increase in blood flow during contractions has been attributed to a greater proportion of perfused capillaries. However, intravital microscopic observations revealed that about 90% of capillaries were perfused at rest. Similarly timed intraarterial injections of fluorochrome showed that all capillaries were perfused at rest within 20sec in both glycolytic (TAG) and oxidative (TAO) part of rat tibialis anterior and about 30% within 7sec. This increased to 90% with threshold and to 96-98% with maximal stimulation. However, flow measured by microspheres increased 5 times with threshold and more than 10 times with maximal stimulation. Thus enhanced velocity of flow rather than a higher proportion of perfused capillaries would seem to be more important for the increase in flow in contracting muscles. Velocity of red blood cells (Vrbc) measured in glycolytic (TAG) or mixed (spinotrapezius) muscles was similar at rest (300±20 and 274±20um/sec respectively) and increased by 30-40% during contractions at 1 or 6Hz, the increase being greater with increasing frequency or repeated contractions. In oxidative muscles (soleus, S) Vrbc was lower and increased less during contractions. S had a greater intermittency of capillary flow than TAG during contractions at 1Hz, and a smaller dilatation of terminal arterioles. Thus increased flow during muscle contractions is met mainly by increased Vrbc and decreased intermittency of flow in glycolytic, but not in oxidative muscles, where rather sluggish flow through many parallel channels can contribute to better substrate delivery. Chronic activity (stimulation of TA at 10Hz for 8h/d for 7 days) increased the proportion of oxidative fibres, CD, capillary diameters, resting Vrbc and flow per capillary; intermittency of flow was also increased resembling that in S; there was only a small increase in Vrbc during contractions. The size of the whole vascular bed estimated by casts increased by 60±11%, due to increased CD and increased number of vessels larger than 10μm. Arterioles were wider after only 3 days of stimulation. Thus chronic electrical stimulation results in remodelling of the whole vascular bed. Functional adaptation of capillary microcirculation seems to improve substrate delivery due to increased flow per capillary, increased CD and increased intermittency of flow.

45.6

STEREOLOGY: USE OF A PHYSICAL MODEL FOR TESTING LENGTH AND SURFACE AREA DENSITY EQUATIONS. T.H. Adair, M.L. Wells*, and J-P. Montani*. Department of Physiology & Biophysics, Univ. Miss. Med. Ctr., Jackson Mississippi 39216

A physical model was used to test our stereological methods for determining length density (Lv), surface area density (Sv), and volume density (Vv) of capillaries. Boiled spaghetti was mixed with agar in a 78 mm long cylinder. The mixture was cut into 13-14 evenly spaced slabs and stained with toluidine blue. The long (a) and short (b) axis of each elliptical profile was measured at 25X using a computerized image analysis system. Five separate trials were performed with the total length of 12 strands of spaghetti ranging from 1200 mm to 2400 mm. Thus the amount of bending of the spaghetti strands (tortuosity) increased as the length of the spaghetti was increased. Actual values of Lv, Sv, and Vv were compared against values calculated using the equations shown below, where A_t is the test area.

$$Lv = \frac{\sum a/b}{\sum A_t} \qquad Sv = \frac{\sum 2\pi a}{\sum A_t} \qquad Vv = \frac{\sum \pi ab}{\sum A_t}$$

Measurements of over 1000 elliptical profiles in the five trials have demonstrated that the above equations can accurately estimate Lv, Sv, and Vv with less than 5% error over the entire range of tortuosity. Classical methods that do not incorporate tortuosity underestimated Lv and Vv in all trials, and the error became greater as the tortuosity increased. (Supported by HL11678, HL02117, and HL42402).

46.1

COMPARATIVE ELECTROPHYSIOLOGICAL EFFECTS OF A NEW CHEMICAL CLASS OF ANTI-ARRHYTHMIC AGENTS, 3,7-DIHETEROBICYCLONONANES, IN THE 1-4-DAY-OLD INFARCTED DOG HEART. T. Fazekas*, P. Mabo*, K.D. Berlin*+, B.J. Scherlag and R. Lazzara. VA Medical Center/University of Oklahoma Health Sciences Center, Oklahoma City, OK 73104; +Oklahoma State University, Stillwater, OK 74078.

The actions of 7-benzyl-7-aza-3-thiabicyclo[3.3.1] nonane hydroperchlorate (BRB-I-28) and its derivatives (GLG-IV-78, GLG-V-13) were studied and compared to equivalent doses of lidocaine, 3 and 6 mg/kg i.v. The experiments were performed 24-96 hours after two-stage ligation of the left anterior descending coronary artery in 13 anaesthetized dogs. Programmed premature stimuli or rapid intermittent 3-beat-bursts (240-420/min) were delivered to the right ventricle to induce sustained monomorphic ventricular tachycardia (SMVT). In the control state, SMVT was inducible in 5/13 dogs (335±73 bpm). After the administration of lidocaine, SMVT was unmasked in 7 dogs which were previously non-inducible. Sustained reentry was unmasked by 3 mg/kg lidocaine in 3 dogs (300±67 bpm) and by 6 mg/kg in 4 (283±52 bpm). BRB-I-28 prevented inducibility in 2/5 and slowed SMVT in the other 3 (347±98 to 240±87; $p < 0.01$); a proarrhythmic action was seen in 2. GLG-IV-78 was given to nine animals: it prevented SMVT in 2 dogs, but not in the other 3 (294±82 bpm). The actions of GLG-V-13 were considerably different: None of the 5 dogs with control SMVT was inducible after the administration of this compound. Moreover, GLG-V-13 markedly slowed heart rate (152±25 to 110±20 bpm, $p<0.01$); increased AH interval (57±8 to 66±7 msec, $p<0.05$); ventricular effective refractory period (142±14 to 187±18 msec, $p<0.001$) and induced QT interval prolongation. All three agents slightly but significantly prolonged HV interval. This new chemical class appears to have combined properties of the Vaughan-Williams groups I, II and III.

46.2

RACING HEART RATES COMPARED WITH DUAL VO2 ANALYSIS IN A DUATHLETE. J. W. Sherman; Dept. Phy. Educ. & Rec., Univ. British Columbia, Vancouver B.C., CANADA.

A case study is presented comparing continuous heart rate (HR) tracings during two successive World Cup Duathalons (Run 5K, Cycle 30K, Run 5K) with a dual VO2max test (treadmill VO2max immediately followed by a cycling VO2max). The study was undertaken to investigate the use of a heart rate moniter as an objective performance tool in comparing competative results. The studies' subject (male, age 28, Ht 192, Wt 79kg) placed 1st in the initial competition (WC-Vanc) with no close challengers; yet two weeks later, with a greater perceived effort, placed 2nd in the subsequent World Cup Event(WC-Anah). The continuous racing HR's revealed an average HR of 168.38 bpm during WC-Vanc, and an average HR of 175.56 bpm during the subsequent WC-Anah event. Laboratory testing completed four days after the WC-Anah event revealed a VO2max of 73.7(run) and 66.9(cycle) ml/min/kg and a HRmax of 186bpm(WORKLOADmax of 12 mph & 8% grade, and 400 watts). Comparing data shows our subject operating at 90.53% of his HRmax (74.8 % of VO2max) during WC-Vanc and 94.39% of his HRmax (84.01% of VO2max) during WC-Anah. One month post testing our subject won the World Championships in the Duathalon. The racing HR data, obtained with a Polar Vantage X-L moniter, compared with laboratory data offers new insight into the exercise intensity and efficiency of an elite multisport athlete. Further work needs to be done to establish the relative contributions of environmental stressors, state of prerace training, and perceived race intensity upon variations in race to race continuous HR tracings. The study was funded by MED+SPORT and UBC Sports Medicine Laboratory.

46.3

CARDIOVASCULAR RESPONSE TO ARM EXERCISE IN PATIENTS WITH HEART TRANSPLANT OR HEART FAILURE. Steven J. Keteyian, Charles R.C. Marks*, T. Barry Levine*, Arlene B. Levine* and Paul D. Stein. Henry Ford Heart and Vascular Inst., Detroit, MI 48202

To determine the cardiovascular response of patients with heart transplant (HT) and heart failure (HF) during sitting, dynamic arm exercise, 13 males with HT (age=52±2, mean±SE) and 14 males with HF (age=52±3, ejection fraction=22±2) were compared to 10 male controls(C)(age=51±2). Subjects exercised using a Monarch Arm Ergometer. Heart rate (HR), cardiac output (CO_2-rebreathing) and systolic blood pressure (SBP) were measured at rest and during workloads which represented first 50% and then 75% of a previously determined maximum.

	HR(min^{-1})			SV($ml \cdot beat^{-1}$)			SBP(mmHg)		
	Rest	50%	75%	Rest	50%	75%	Rest	50%	75%
HT	92±3	111±3	120±3*	60±3	88±6	100±5*	131±4	175±6	189±6*
C	62±3	92±3	109±3*	101±8	129±7	132±6**	126±5	168±8	186±9*
HF	77±3	102±3	112±4*	63±4	90±7	93±9**	113±4	146±7	156±7*

SV=stroke volume; paired t-test; *$p<0.01$ for rest vs 50, rest vs 75 and 50 vs 75; **$p<0.01$ for rest vs 50 and rest vs 75

All three study groups increased both HR and SBP throughout arm exercise. The absence of an increase in SV from the 50% to 75% workload in HF and Control subjects differed from HT subjects. This suggests that the plateau in SV observed in innervated subjects during dynamic arm exercise is regulated by the autonomic nervous system.

46.4

EFFECTS OF MENSTRUAL CYCLE AND EXERCISE ON THE FRACTAL DIMENSION OF HEART RATES IN COLLEGE AGE WOMEN. James Watrous and Mary Nguyen*. Biology Department St. Joseph's Univ. Phila. PA. 19131

R-R intervals from ECG tracings of college-age women during three phases of the menstrual cycle (proliferation, ovulation, menses) both pre and post exercise were used to estimate the fractal dimension (FD) of heart rates. Seated subjects had their ECG recorded for 90 sec followed by 3 min of light exercise on a stationary bicycle. ECG recordings were obtained for 90 sec after exercise. The method of Glenny et.al. (1991) was used to determine the FD. Data are presented as log-log plots of the number of time intervals averaged vs the relative dispersion (SD/mean). Linear regression was used to obtain the best fit. Results of this investigation show that: (1) each subject exhibits a distinctive increase in FD for one of the three menstrual cycle phases; (2) the increase in FD for one phase was retained over all menstrual cycles analyzed, and (3) there is a decrease in the FD of post-exercise R-R intervals. This study was supported in part by grant #11400 from Hewlett-Packard.

46.5

CHANGES IN LEFT VENTRICULAR VOLUMES DURING TWO MINUTES OF MAXIMAL HANDGRIP EXERCISE AND POST-EXERCISE OCCLUSION. Denise L. Smith, James E. Misner, Eddie Meirelles, Tim Patrick. Skidmore College, Saratoga Springs, NY. 12831; Univ. of Illinois, Urbana, IL. 61801

M-mode echocardiography was used to measure end-diastolic ventricular volume (EDVV), end-systolic ventricular volume (ESVV), and stroke volume (SV) in 9 healthy, young male subjects at rest, during 2 min. of maximal handgrip exercise, and 2 min. of post-exercise occlusion.

condition	time(sec)	EDVV(ml)	ESVV(ml)	SV(ml)
rest		140.4	57.0	83.4
handgrip	30	130.7	49.0	81.7
	60	141.9	54.2	87.7
	90	124.8	43.9	81.0
	120	141.9	51.0	90.9
occlusion	150	143.5	49.8	93.8
	180	142.4	56.9	85.5
	210	150.4	59.6	90.8
	240	144.7	55.7	89.0

LVV changed little during sustained maximal handgrip exercise and post-exercise occlusion, despite observed significant changes in HR and BP and apparent increased sympathetic drive.

46.6

CORONARY AND MYOCARDIAL FUNCTIONAL DEPENDENCE ON PERFUSATE DISSOLVED OXYGEN. Ronald W. Millard, Anthony J. McGoron and Ingrid L. Grupp. University of Cincinnati, Cincinnati, OH 45267-0575.

Fluorochemical compounds posses a higher oxygen solubility (>20X) than does physiological saline. We used the emulsified form (FCE) to test the hypothesis that heart ventricular function depends upon perfusate oxygen content ($[O_2]$) not oxygen partial pressure (pO_2). Studies were conducted at constant pO_2 (600 and 200 torr) in 12 Langendorff isolated rat hearts (55 mmHg aortic pressure, 37°C) perfused with Krebs-Henseleit (KH) buffer solution supplemented with the FCE containing Perfluorooctylbromide (test, n=6) or with KH alone (controls, n=6). At selected points arterial and venous pO_2 and $[O_2]$ and coronary flow (CF) were measured. O_2 consumption (O_2 cons) was calculated. Heart rate (HR) and left ventricular dP/dt (LVdP/dt) were continuously monitored. HR, LVdP/dt and O_2 cons decreased and CF increased significantly when perfused with KH alone with pO_2 reduced to 200 torr. O_2 cons, LVdP/dt and HR were all significantly greater following FCE perfusion relative to the control hearts at pO_2 of 200 torr. During recovery (to pO_2 of 600 torr), 3 of 6 control KH hearts fibrillated. None of the test hearts fibrillated during recovery but O_2 cons, HR and CF were significantly lower during recovery relative to baseline. Conclusion: FCE confers significant oxygen transfer to heart cells and restores cardiac function toward normoxic values recorded during KH perfusion even at pO_2 of 200 torr.

46.7

FITNESS AND HEART RATE VARIABILITY. Stephanie Tuck and Richard L. Hughson. Dept of Kinesiology, Univ. Waterloo, Waterloo, Ont. N2L 3G1

A long standing question in exercise physiology concerns the relative balance of parasympathetic and sympathetic nervous system (PNS and SNS) activity in the heart rate control of endurance trained and untrained subjects. We have used coarse graining spectral analysis of heart rate variability (HRV) to estimate PNS and SNS indicators in two groups of subjects with different fitness levels: Group A had VO_2max of 57 - 62 ml/kg/min, and Group B had 30-42 ml/kg/min. Measurements were made at rest and at 30, 60, and 110% ventilatory threshold (T_{VENT}). The PNS indicator was higher in Group A at rest and at each level of exercise. In contrast, the SNS indicator was higher at all levels in the less fit Group B. Due to individual variations and relatively small sample sizes (n = 5 per group), statistical significance was observed only at 60% T_{VENT} for the PNS indicator. These data obtained by simple, non-invasive methods are in agreement with early pharmacological studies of PNS and SNS control of HR, as well as a recent spectral analysis study of HRV. The data raise some interesting questions about potential differences in PNS and SNS contributions to HR control in fit vs. non-fit subjects. Perhaps the higher PNS and lower SNS tones reported at rest are maintained during exercise in fitter individuals.

Supported by Heart and Stroke Foundation of Ontario.

46.8

INCREASED LEFT VENTRICULAR CONTRACTILITY IN MARATHON RUNNERS AFTER UNACCUSTOMED HIGH WEEKLY TRAINING MILEAGE

R.H. Dressendorfer, A.M. Hauser*, G.C. Timmis*, and C.E. Wade. Division of Cardiovascular Diseases, William Beaumont Hospital, Royal Oak, MI 47701

We analyzed resting echocardiograms, 12-lead ECGs, and blood samples on 21 male marathon runners before and after their training distances were abruptly raised by an average of 93 km/wk (99%). Following 15 d of the higher mileage, 12 runners (EHR group) had elevated (≥ 10 b/min) heart rates in the seated position; their mean HR increased from 54 to 69 b/min ($p<0.05$). Mean HR was unchanged (52 to 52 b/min) in the other 9 runners (UHR group). Age, physical characteristics, marathon times, training pace, and serum markers of muscular damage were similar between the two groups. Systolic blood pressure (SBP) decreased from 130 to 121 mm Hg in EHR and from 128 to 120 mm Hg in UHR ($p<0.05$ for both groups). Left ventricular (LV) internal diameters at end-systole and end-diastole (LVIDd), stroke dimension, posterio and septal wall thicknesses, ejection fraction, and the ratio of SBP/LVIDd were not significantly different between the groups and were not significantly changed for either group. In EHR, the rate of circumferential fiber shortening and fractional shortening increased from 1.10 to 1.34 circ/sec ($p<0.05$) and from 42% to 45% ($p<0.05$), respectively, both becoming higher than in UHR ($p<0.05$). R-wave voltage in leads II and V4-6 increased ($p<0.05$) and serum K^+ levels increased (4.4 to 4.6 mEq/L, $p<0.05$) in EHR; each of these also became higher than in UHR ($p<0.05$). Elevated resting HR after unaccustomed high training mileage is associated with increased LV contractility, unchanged stroke performance, and increased R-wave voltage and serum K^+ level.

46.9

NONINVASIVE MEASUREMENT OF CARDIAC OUTPUT WITH IMPEDANCE CARDIOGRAPHY DURING EXERCISE. R.W. Gotshall. Colorado State Univ., Fort Collins, CO 80523

Measurement of CO in humans expands the capability to evaluate and interpret cardiovascular function during exercise. Impedance cardiography (IC) has been applied to the noninvasive measurement of CO during exercise with varying success. Artifact in the signal makes the interpretation of the impedance cardiogram difficult. This study evaluated the use of an ensemble averaging computer program, designed to reduce artifacts in the impedance signal, to permit more reliable measurements of CO during exercise. 5 subjects exercised to maximum on the bicycle ergometer using an incremental protocol, and 4 subjects exercised at steady state for 5 minutes. Oxygen uptake (VO_2) was measured throughout the exercise. CO was linearly related to VO_2 by the regression: $CO=3.55 + 5.31VO_2$, similar to the relationship described by Jones (1988) for similar populations: $CO=5.37 + 5.08VO_2$. The intercepts differ, but the slopes are the same. For steady state exercise, CO was stable during the steady state exercise. These results indicate that the changes in CO can be described during exercise by the use of IC when exercise signal artifacts are reduced.

46.10

METABOLIC ADAPTATIONS OF THE RAT HEART TO CHRONICAL VOLUME-OVERLOAD. Josef Moravec, Amin Guendouz*, Zainab El Alaoui-Talibi*. Laboratoire d'Energétique et de Cardiologie Cellulaire 21 033 Dijon, France.

Chronical volume-overload was induced in young rats by surgical opening of the aorto-caval fistula. The animals were sacrificed 3 months later and their hearts perfused in vitro with 11mM glucose and 1.2mM palmitate. The measurements of 14C-palmitate conversion into 14CO2 confirmed an impaired ability of hypertrophied hearts to utilize long chain fatty acids. This alteration, which may be related either to decreased activity of long chain acylCoA synthetase or to decreased tissue levels of L-carnitine, resulted in a substrate limitation of the respiratory chain function. This is reflected by a significant reduction of the oxygen consumption rate observed under standard perfusion conditions. When oxygen consumption rate as well as the parameters involved in control of mitochondrial respiration were examined over the range of increasing work loads, it appeared that, at any QO2, the hypertrophied hearts operated at lower ATP/ADPf.Pi ratio. At the same time, mitochondrial pyridine nucleotides were maintained more oxidized. It would seem that hypertrophied hearts compensated the lack of oxidizable substrate by an excessive decrease of cytosolic phosphate potential. This may compromize their mechanical activity and give rise to an acute failure. The administration of propionyl-L-carnitine partly restored tissue levels of CP and significantly improved mechanical activity of overloaded hearts.

46.11

EFFECTS OF CARNITINE DEFICIENCY ON CARDIAC CONTRACTILE FUNCTION AND GLUCOSE OXIDATION. D.J. Paulson, B.A. Wolf, and D.F. DiDomenico. Chicago College of Osteopathic Medicine, Dept. of Physiology, Downers Grove, IL 60515.

Clinical studies have suggested that myocardial carnitine deficiency is associated with cardiomyopathy. The purpose of this study was to establish a small animal model of carnitine deficiency and to examine the cardiac consequences. Sodium pivalate (20mM) was added to the drinking water of male Sprague-Dawley rats weighing between 135-160 g for 11 to 12 weeks. Sodium bicarbonate (20mM) was added to the drinking water of control rats. *In vivo* myocardial carnitine content was determined along with *in vitro* myocardial contractile function and glucose oxidation rates of isolated perfused working hearts subjected to 90 minutes of global low flow ischemia followed by 30 minutes of reperfusion. The pivalate treated animals had a significant decrease in total myocardial carnitine levels (pivalate: 2352±152 vs control: 5812±406 nmoles/g wet wt.). Because of this carnitine deficiency, glucose oxidation was enhanced during the working heart mode (pivalate: 0.68±0.13 vs control: 0.10±0.02 μmoles/g/min) and the reperfusion period (pivalate: 1.44±0.35 vs control: 0.34±0.11 μmoles/g/min). No significant differences were seen in left ventricular systolic pressure, end diastolic pressure, heart rate, aortic flow, coronary flow, cardiac output, +dP/dt, -dP/dt, or dP/dts. These findings show that a 60% myocardial deficiency of L-carnitine for an 11-12 week duration increases myocardial glucose oxidation rate but does not adversely affect cardiac contractile function. Further experiments will determine whether a longer duration of carnitine deficiency will adversely affect myocardial function.

46.12

CARCIAC OPIOIDS: EFFECTS OF VENTRICULAR DENERVATION. Barbara A. Barron, Lawrence X. Oakford, John F. Gaugl, Nancy Longlet, Carl E. Jones, James L. Caffrey. Texas College of Osteopathic Medicine, Ft Worth, TX 76107

Our data clearly indicates that enkephalins originate in cardiomyocytes. Frozen tissue sections were incubated with an antibody to Met-enkephalin-arg-phe (ME-ap) and a fluorescent-labelled second antibody. ME-ap is the carboxyl terminal peptide of proenkephalin and the antibody crossreacts with peptide B and proenkephalin. The fluorescence is observed in ordered lines perpendicular to the longitudinal axis of the myocyte, concentrated around the intercalated disc, suggesting an opioid function in communication between cells. This also suggests a secretory mechanism which utilizes the intercalated disc to export peptides. The fluorescence was absent from sections incubated with normal rabbit serum or antibody preabsorbed with ME-ap. Proenkephalin content measured with the same antibody is more than 6 times greater in the ventricle than the atria (130 vs 24 fmol/mg protein). However, ME immunoreactivity (ir) is uniformly distributed throughout the myocardium (2.5 fmol/mg protein). This differs from the catecholamines, which are more concentrated in the atria and further supports the localization of enkephalins in the myocardium as well as in cardiac nerves.

Dog ventricles were surgically denervated or sham-operated and tissue collected 4 weeks later. Denervation produced the expected decrease in ventricular catecholamine content and also decreased atrial norepinephrine concentration. Proenkephalin-ir was unchanged by denervation however the product, ME, was decreased in the denervated ventricles (1.5 fmol/mg protein). This indicates that neuronal input to cardiomyocytes regulates processing and/or release of enkephalin.

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46.13

ENDURANCE TRAINING DECREASES MYOCARDIAL CATECHOLAMINE LEVELS. Brian H. Foresman, Eugene E. Quist, Barbara A. Barron, and Patricia A. Gwirtz. Departments of Medicine, Physiology & Pharmacology. Texas College of Osteopathic Medicine, Fort Worth, TX. 76107-2699

Endurance training (ET) alters cardiovascular dynamics and leads to a reduction in heart rate during rest and exercise. These changes may result from changes in cardiac neuronal catecholamine levels. Studies in rats measuring tissue catecholamine levels have failed to demonstrate any consistent response to ET. In contrast, longitudinal studies in humans using pharmacologic blockade (i.e., atropine and metoprolol) suggest that training bradycardia may be the result of reduced myocardial catecholamines or altered receptor function. We determined myocardial catecholamine levels in a canine model of ET. Three animals underwent eight weeks of treadmill exercise to reduce resting and exercise HR by at least 10%. Another five animals were cage rested to obtain unconditioned (UC) controls. The animals were anesthetized with pentobarbital, the ventricles were surgically removed and then analyzed for norepinephrine (NE) and epinephrine (EPI) contents. The UC animals had significantly higher levels ($p<0.02$) of NE in the right (42.1 ± 12.8 vs 18.8 ± 0.7 pmol/mg protein) and the left ventricles (41.3±8.5 vs 17.4±3.6 pmol/mg protein) and intraventricular septum (48.3±6.2 vs 16.2±1.2 pmol/mg protein) as compared to ET animals. Training did not alter EPI levels in the ventricles nor the proportion of NE between ventricles. From this data we conclude that ET decreases resting ventricular NE levels, and, this reduction may contribute to the intensity of training-induced bradycardia and the pattern of myocardial responses seen during exercise.

46.14

AUTONOMIC CONTROL OF THE HEART RATE DURING DYNAMIC EXERCISE IN ATHLETES. R. Golfetti*; A.M. Catai*; B.C. Maciel*; J.A. Marin Neto*; L.E.B. Martins*; E.C. Lima Filho*; A. Matsuura* and L. Gallo, Jr. UNICAMP, USP, UFSCAR, Campinas, SP, Brazil, 13083.

Aiming to elucidate the sympathetic and parasympathetic contribution in the control of heart rate (HR) during dynamic exercise (DE), submaximal intensity cycle ergometer tests were applied in 14 athletes, 8 males (M) and 6 females (F), including speeders and mean-distance runners, after a 45 day period of resting. It was utilized a discontinuous step type test (4 min.periods of DE with rest in between), with 25, 50 and 100 watts (W) for both sexes and an additional 150 W for M. The results are summarized as follow: 1) the rest bradycardia was greater in F than M; 2) during the first 10 s of DE, the increment of the fast response of the HR (vagus dependent) was unrelated to the applied power for both sexes; 3) under low power (25 W), during the stabilization of HR (after 2 min.), F showed greater magnitude of tachycardia than M; 4) At 50 W (F) and 100 W (M), it was observed the appearance of a slow (sympathetic dependent) increase in HR (HR 1-4 min). So, F compared to M, present at the same power, a lower vagus reserve and a higher sympathetic stimulation, as a mechanism to increase HR during DE.

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COMPARATIVE PHYSIOLOGY

47.1

CHANGES IN BLOOD CHEMISTRY OF ANTARCTIC TELEOSTS IN RESPONSE TO EXERCISE

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Fishes endemic to Antarctica are somewhat anaemic, relative to temperate species, while the *Channichthyidae* lack functional respiratory pigments, possibly reflecting the greater availability of oxygen. Using chronically cannulated animals held at 0-2°C, post-branchial blood samples were obtained from *Notothenia neglecta* and *N. rossii* (haematocrit ca. 15%), and *Chaenocephalus aceratus* (Hct <1%), at rest and following a 3min period of induced maximal exercise.

Both *N. neglecta* and *N. rossii* showed a decrease in pHa (ca. 7.9 to 7.6) and PaO_2, but showed little change in Hct or [lactate]. In contrast, *C. aceratus* showed little change in pHa and a small increase in PaO_2 due to hyperventilation. Catecholamine titres were low in all specimens (ca. 2nM), and showed minimal change with exercise. Changes in pHa were best correlated with a rise in $PaCO_2$, suggesting an unusual response to exercise in Antarctic teleosts of a respiratory, but not a metabolic acidosis.

C. aceratus required over 36h to re-establish baseline values, while *N. neglecta* took <24h to show full recovery. Although under normal circumstances environmental oxygen is unlikely to be limiting, the residual benefit of red blood cells appears to be significant in the restoration of acid-base balance following disturbance.

Supported by the NERC (grant GR3/7106) and the BAS Summer Visitors programme.

47.2

THE EFFECT OF WATER TEMPERATURE AND EXERCISE ON THE HEART RATE, STROKE VOLUME AND CARDIAC OUTPUT OF THE LARGESCALE SUCKER (*Catostomus macrocheilus*). Alan S. Kolok* and Anthony P. Farrell. Simon Fraser University, Burnaby, British Columbia, Canada, V5A 1S6.

Heart rate (HR), stroke volume (SV) and cardiac output (Q) were measured using an ultrasonic flowprobe surgically fitted around the ventral aorta of adult largescale suckers. Measurements were made during the summer (16°C), fall (10°C) and winter (5°C) while the fish were at rest and while swimming at their critical swimming speeds. Whereas resting and maximal Q values increased with temperature, the factorial scope for Q was not related to temperature in a simple fashion. The factorial scope for Q at 16°C was not significantly different than that at 10°C, but both were greater than the scope for Q at 5°C which was essentially zero. The increase in Q at 16°C was the product of a 79% increase in HR, and a 34% increase in SV. At 10°C, the increase in Q was the product of a 78% increase in HR and a 123% increase in SV. Swimming at 5°C significantly increased HR (23%), but did not significantly increase SV. Thus, the degree to which Q was increased by SV and HR was strongly dependant upon acclimation temperature.

(supported by Science Council of British Columbia)

47.3

TUNA HEARTS DO IT DIFFERENTLY! A.P. Farrell, J.E. Keen, P.S. Davie[+], C.E. Franklin[+], J.A. Johansen and R.W. Brill[*]. Simon Fraser Univ., Canada, ([+]Massey Univ., New Zealand & [*]Kewalo Basin, Hawaii).

Tuna hearts have the highest cardiac and myocardial power outputs of any fish. Recent work demonstrates that heart rate, E-C coupling and reliance on a coronary circulation is more akin to mammalian hearts. Heart rates are around 100 bpm in spinalectomized tuna and perfused tuna hearts; values up to 250 bpm are reported during swimming. Heart rates in other fishes are lower than ~120 bpm[1]. Furthermore, this 2-3 fold range for increasing heart rate in tuna is larger than in other fishes, raising the possibility that tuna hearts, like mammalian hearts, are primarily frequency-modulated[2]. Other fishes are volume-modulated. Force generation in tuna atrial strips is reduced by ~30% with ryanodine (a blocker of sarcoplasmic reticulum calcium release). This indicates that like mammals, the cardiac SR plays a significant role in E-C coupling[3]. In contrast, contractile force in other fishes is almost entirely mediated by sarcolemmal calcium influx. Unlike in rainbow trout, perfused skipjack tuna hearts fail to work at physiological levels without perfusing the coronary circulation.[2] This observation leads to the conclusion that tuna hearts are obligately dependent on their coronary circulation.

[1]Farrell, A.P. 1991. Physiol. Zool., 64:1137. [2]Farrell et al. 1992. Can. J. Zool. In press. [3]Keen et al. 1992. Can. J. Zool. In press.

47.4

EMPEROR PENGUIN OXYGEN CONSUMPTION, HEART RATE AND BLOOD LACTIC ACID CONCENTRATION DURING VARIABLE SWIMMING RATES. Gerald L. Kooyman* and Paul J. Ponganis. Scholander Hall, Scripps Institution of Oceanography, La Jolla, CA 92093

Emperor penguins were swum in a 1 m^2 x 4 m section of a 20 m long water mill. Water flow and temperature were set at 1 m/s and 3°C, respectively. Higher swim rate was induced by changing weights on a line attached through a series of pulleys to the dorsal feathers of the immersed bird. As much as 4 kg of weight was loaded in this way which was estimated to be equivalent to the effort required to swim at 6 m/s. Resting VO_2 was 6.7 ml/O_2/kg min and maximum VO_2 was 47 ml O_2/kg min. Surface and submerged heart rates increased linearly and at VO_{2max} were about 205 and 165 beats/min, respectively. There was no increase in blood lactic acid concentration [LA] until VO_2 exceeded 25 ml O_2/kg min. At the highest, VO_2 [LA] reached >6 mmol. Compared to other animals of approximately the same body mass, emperor penguins have slightly greater aerobic capacity than seals, and equivalent to sea lions, goats and emus. It is estimated that minimum transport cost falls between 3 and 6 m/s. (Supported by USPHS HL 17731; NSF DPP 86-13729)

47.5

ASSESSING THE PHYSIOLOGICAL LIMITS OF EXERCISE PERFORMANCE IN BOTTLENOSE DOLPHINS. Terrie M. Williams, William A. Friedl*, and Jeffrey E. Haun
NOSC Hawaii Lab, Kailua, HI 96734

Swimming speed and duration of submergence are constrained by the balance between oxygen stores and the energetic demands of exercise in marine mammals. To determine the physiological responses associated with aquatic performance in these animals, we examined the relationship among aerobic and anaerobic costs of exercise, oxygen stores, and level of effort in swimming and diving bottlenose dolphins (Tursiops truncatus). Many of the energetic and cardio-respiratory responses of exercising dolphins were similar to those of terrestrial mammals. However, the dolphin's dynamic metabolic scope and level of maximal oxygen consumption ($\dot{V}O_{2max}$) fell short of those reported for elite terrestrial athletes such as horses and dogs. $\dot{V}O_{2max}$ ranged from 19.8 to 29.4 $ml O_2 . kg^{-1} . min^{-1}$ (7 - 11 times $\dot{V}O_{2std}$) for 145 kg dolphins. Oxygen stores were 33 $ml O_2 . kg^{-1}$ body weight and were an important avenue of metabolic support during diving and swimming at routine speeds (2.1 $m . s^{-1}$). Because these stores are often overlooked during conventional exercise testing, new methods for evaluating physiological responses to exercise should be considered for marine mammals.

47.6

GLUCOSE AND LACTATE METABOLISM IN SKELETAL MUSCLE OF LARVAL SALAMANDERS (*Ambystoma tigrinum*). Steven J. Wickler, Todd T. Gleeson* and Erica L. Wagner*. California State Polytechnic University, Pomona, CA 91768 and Univ. of Colorado, Boulder, CO 80309

Vigorous exercise in vertebrates entails lactate accumulation. Studies on reptiles indicate that the major pathway for this lactate removal is through glycogen resynthesis rather than oxidation--in contrast to mammals. The present study examined the *in vitro* ability of hindlimb muscles of an amphibian to utilize glucose and lactate. Isolated muscles from larval *Ambystoma* were stimulated to fatigue and then incubated in a medium of pH 7.2 containing glucose (1 mM) and bicarbonate (15 mM) to mimic the post-exercise milieu. Muscles were incubated with either U-^{14}C-glucose or U-^{14}C-lactate. Evolved CO_2 was trapped and counted. After one hour of incubation, muscles were removed from the incubation medium and quickly frozen on dry ice. Glycogen was isolated and counted. Oxidation rates and glycogen incorporation were expressed as glucose equivalents. Oxidation rates of lactate were almost 12x higher than for glucose (0.404 ± 0.081 vs 0.035 ± 0.007 µmoles glucose equivalents • g^{-1} • hr^{-1}, respectively). Incorporation of lactate into glycogen was more than twice that for glucose (1.85 ± 0.29 vs 0.75 ± 0.07 µmoles glucose equivalents • g^{-1} • hr^{-1}, respectively). To compare the muscle's preferential handling of lactate, we calculated the ratio of µmoles lactate converted into glycogen to that of µmoles lactate oxidized. This ratio, 4.58:1, is similar to that of most other lizards as well as toads. This is in contrast to that in rats which demonstrate the inverse, i.e, a preference for oxidation of lactate. The current study provides persuasive *in vitro* evidence that the recovery strategy of larval salamanders emphasizes not oxidation but glycogenesis. (Supported by an NSF grant, DEB 86-15603, to TTG and a sabbatical leave grant to SJW).

47.7

REGULATION OF GLYCOGEN REPLENISHMENT IN POST-EXERCISE SKELETAL MUSCLE OF A LIZARD. Todd T. Gleeson*
(SPON: R.S. Mazzeo). Univ. of Colorado, Boulder, CO. 80309-0334.

Reptilian skeletal muscle exhibits an enhanced glyconeogenic capacity. Glyconeogenesis appears to be the primary pathway for glycogen resynthesis as well as for lactate removal. Lactate carbon is incorporated in glycogen by skeletal muscle at 2 - 5 times the rate at which glucose carbon is incorporated. In vivo, only a small fraction of the post-exercise lactate pool is oxidized. These characters are very different than those of rat and mouse muscle. Mammalian muscle glycogen resynthesis is fueled primarily by glucose, is depressed by corticosterone and epinephrine, and is enhanced by acidic pH and by insulin (Bonen et al., AJP 258: E693). Initial study suggests that reptilian glycogen restitution is regulated differently. Over a pH range of 6.5 - 8.0, glyconeogenic capacity is not enhanced under acidic conditions. Corticosterone does not influence glyconeogenesis, and epinephrine appears to stimulate lactate incorporation into glycogen, but have no effect on glucose incorporation. Post-exercise Epi (15 ng/ml) enhances lactate incorporation in white muscle 2- to 2.5-fold in the presence of both LA (15mM) and glucose (8.5mM), and 2-fold in red muscle when LA was the sole substrate. Epinephrine does not enhance glycolysis under these conditions. Insulin (0 -50 mU/ml) also has no significant effect on glycogen restitution or lactate incorporation into glycogen. Data indicate that several of the effectors of mammalian glycogen resynthesis have no effect on reptilian muscle, while Epi, which has no effect in mouse, stimulates lizard glycogen restitution. One possible explanation for this difference is the reptilian emphasis on glyconeogenic rather than glycogenic pathways for glycogen resynthesis. Supported by NSF DEB 8616503.

47.8

CHRONIC STIMULATION OF REPTILIAN MUSCLE: IS PLASTICITY A PRIMITIVE FEATURE OF VERTEBRATE SKELETAL MUSCLE? S.D. Nichols and S.L. Lindstedt. Northern Arizona University, Flagstaff, AZ 86004.

Vertebrate skeletal muscle is composed of a mosaic of fiber types differing in their speed of contraction as well as energy and oxygen requirements and fatigability, characteristics that were once considered genetically-fixed properties of muscle. Salmons and Vrobova developed the technique of using chronic electrical stimulation to exogenously stimulate fast muscles in both the cat and rabbit; these experiments demonstrated shifts in metabolic and contractile properties solely in response to the type of nervous input received by the muscle. Is this phenotypic plasticity common only to mammals or do other vertebrate muscles respond similarly to shifts in stimulation frequency? To test this hypothesis we subjected the iliofibularis muscle of Savannah Monitor lizards to daily (8h/d, 5d/w) high frequency (10Hz) stimulation for 6 weeks. Following stimulation, the muscles were removed for histochemical and ultrastructural analysis. Comparing the muscles with their non-stimulated contra-lateral controls, the stimulated muscles showed: 250% increase in mitochondria, 60% reduction in Sarcoplasmic Reticulum, and a 3000% increase in intracellular lipids. These results suggest that reptilian muscle responds with the same degree of plasticity as mammalian muscle, despite the lack of a cardiovascular system that can satisfy a large aerobic demand. (NIH RO1HL41986; AHA, Flinn Foundation Fellowship)

47.9

STRUCTURE-FUNCTION COUPLING IN THE FASTEST-CONTRACTING VERTEBRATE MUSCLE: THE RATTLESNAKE TAIL-SHAKER MUSCLE. P. Schaeffer and S.L. Lindstedt, Northern Arizona University, Flagstaff, AZ 86004.

The Western Diamondback Rattlesnake (*Crotalus atrox*) can rattle its tail continuously for up to an hour. Rattling frequencies first studied by Rahn 40 years ago; approach 90 Hz, double the frequency of hummingbird and even most insect flight muscle. We examined the electromyography, oxygen uptake and quantitative ultrastructure of the rattlesnake tailshaker muscle to examine the structure-function coupling in what may be the fastest contracting and relaxing large vertebrate muscle. Because the tail muscles were apparently the only muscles active during rattling, we were able to determine the in vivo oxygen uptake of this group of muscles with the animals resting and rattling in a metabolism chamber. The weight-specific oxygen uptake of the tail shaker muscles in these snakes exceeds that reported for any other reptilian muscle. The oxygen uptake exactly parallels the rattling frequency, both have a low Q_{10} (1.4) throughout the range of body temperatures in which the animals are normally active (20-35°C). Below 20°C the Q_{10} of both VO_2 and rattle frequency is about 2.5, suggesting that ,<20°C the system is "supply-limited" and >20°C, "demand-limited." This muscle has no apparent unique structures, rather it is designed to minimize activation, contraction and relaxation times. It may be a model system for studying vertebrate excitation-contraction coupling. (NIH RO1HL41986; AHA, Flinn Foundation Fellowship)

47.10

A COMPARISON OF NORMOTHERMIC DISUSE ATROPHY IN DIFFERENT SUBSPECIES OF A HIBERNATOR IN DIFFERENT MONTHS. Donald F. Hoyt, Steven J. Wickler, and Christie N. Rice-Warner*. California State Polytechnic University, Pomona, CA 91768

During hibernation, locomotory muscles of Golden-mantled ground squirrels (*Spermophilus lateralis*) lose mass. However, the mass-specific activity of citrate synthase increases -- opposite to that in normothermic (i.e. non-hibernating) rats. In the present study we determined the response to decreased activity in normothermic *S. lateralis*. We used animals from two different subspecies: *S. l. chrysodeirus*, from Kennedy Meadows in the Southern Sierra Nevada Mountains (KM); and *S. l. bernardinus*, from Holcomb Valley in the San Bernardino Mountains (HV). Controls were freshly caught animals. Experimentals were housed at room temperature in standard rodent cages (20x26x14cm) for four weeks. We studied KM during August, 1991 and HV during September, 1989. We measured masses of gastrocnemius (GAST), and soleus (SOL) muscles and mass-specific activity of citrate synthase (CS) in whole muscle homogenates of these muscles. These two studies gave different results. The KM animals showed no muscle atrophy but the HV animals showed atrophy in GAST (16%) and SOL (12%). CS activity was unchanged in KM animals but the HV animals showed an increase in CS activity from GAST (31%) and no change in CS activity from SOL. These results may be due to different responses to decreased activity in the two subspecies. This hypothesis is consistent with our observation that CS activities of the two control groups are different. An alternate hypothesis is that the species responds differently in August and September. This would not be surprising in view of the many physiological preparations for hibernation occurring at this time of the annual cycle of this species. Follow-up studies planned for the summer 1992 will test these hypothesis. Partially supported by NIH grant: 1 R15 AR39893-01A2.

47.11

ALLOMETRY OF AEROBIC METABOLISM IN RODENTS: MINIMAL, MAXIMAL AND SCOPE. J. E. P. W. Bicudo, J. H. Jones, A. Jackson and D. Wong. Department of Physiological Sciences, University of California, Davis, CA and Department of Animal Physiology, University of São Paulo, Brazil.

Controversy exists as to the "true" relationship between body size and energy metabolism in mammals. We investigated whether allometric relationships for standard ($\dot{V}_{O_2}$std) and maximal ($\dot{V}_{O_2}$max) rates of O_2 consumption within a single order of mammals, the Rodentia, are different from those of less closely related mammals. We measured $\dot{V}_{O_2}$max and $\dot{V}_{O_2}$std in the largest rodent, the capybara (*Hydrochaeris hydrochaeris*, 50 kg) and another large rodent, the agouti (*Dasyprocta fulginosa*, 3.7 kg), using a treadmill and open-flow system, and combined these data with others from the literature to determine allometric equations for rodents and mammals in general. The inclusion of these large rodents allowed allometric regressions for rodents to be made over a range of body size spanning 10^5. The allometric mass exponents (b in the equation $\dot{V}_{O_2} = aM_b^b$, where M_b is body mass) for rodents differed from those for non-rodents for both $\dot{V}_{O_2}$std (b = 0.681 ± 0.030 [95% CL], n = 180 *vs.* b = 0.727 ± 0.021, n = 212) and $\dot{V}_{O_2}$max (b = 0.756 ± 0.078, n = 12 *vs.* b = 0.870 ± 0.094, n = 24). Furthermore, the rodent regressions were displaced lower (*i.e.*, the values of a in the allometric equations were smaller) for both $\dot{V}_{O_2}$std and $\dot{V}_{O_2}$max than those of the non-rodents. These results indicate that aerobic scope ($\dot{V}_{O_2}$max/$\dot{V}_{O_2}$std) increases less with body size in rodents ($\propto M_b^{0.075}$) than in non-rodents ($\propto M_b^{0.143}$). The results also suggest that the design factors that determine the allometry of metabolism may be more closely related within an order than between orders, resulting in allometric relationships that more closely resemble intraspecific relationships than interspecific. Supported by UC Davis Biomedical Research Support Grant and FAPESP (São Paulo State Science Foundation).

47.12

ACID-BASE EVALUATION UTILIZING STRONG ION DIFFERENCE (SID) IN EXERCISING HORSES. P.L. Ferrante, J.H. Williams and D.S. Kronfeld. Virginia Tech, Blacksburg, VA. Acid-base status was evaluated during exercise utilizing strong ion difference (SID). Based on physical and chemical principles, plasma [H^+] and [HCO_3^-] are dependent on plasma P_{CO2}, and strong ions, Na^+, K^+, Cl^- and lactate (Lac^-). 4 horses on control (CON) diet and 4 on high fat (FAT) diet (10% corn oil, by wt) were used. 2 exercise tests consisting of repeated sprints to exhaustion were performed 2 wks apart. Two horses from each diet group received $NaHCO_3$ (300 mg/kg) dissolved in water intragastrically 1.5 h prior to exercise. The other 2 received an equal volume of water. Treatments were reversed for the second test. During exercise plasma pH, [HCO_3^-] and [Na^+], blood [Lac^-] were significantly greater when horses received $NaHCO_3$. Plasma P_{CO2} was similar between $NaHCO_3$ and water treatments. Blood [Lac^-] was significantly greater during exercise in FAT horses compared to CON. Although P_{CO2} was lower in FAT horses, there was no significant difference between the two diet groups in pH. [HCO_3^-] was less in the FAT group. The increased [Na^+] in horses administered $NaHCO_3$ caused the SID to increase even though [Lac^-] was elevated during exercise resulting in higher pH and [HCO_3^-]. The increased [Lac^-] during exercise in horses on FAT diet was not offset by a change in other strong ions producing a decrease in SID in these horses and resulting in decreased [HCO_3^-]. (Funded by a Pratt Fellowship and Waltham Centre for Equine Nutrition)

47.13

BLOOD ION AND FLUID HOMEOSTASIS DURING AND AFTER PROLONGED EXERCISE IN ENDURANCE HORSES. Gayle Ecker*, Michael I. Lindinger, and Henry Staempfli*. Equine Research Center, School of Human Biology, and Dept. of Clinical Studies, University of Guelph, Ontario, N1G 2W1, Canada.

We monitored hematocrit (Hct), plasma protein (Pr) and ions in horses during a 55 mile endurance competition to understand the effects of prolonged exercise on equine fluid and ion homeostasis. Blood (8 ml) was collected from the jugular vein of 18 horses at rest, mid-ride, immediately post-ride and 1 hour of recovery. Blood was analyzed for Hct and plasma [Na^+], [Cl^-], [K^+], ionized [Ca^{++}], [glucose] and osmolality on site (Nova Statprofile 5 acid-base/ion analyzer); plasma [Pr] was measured by refractometry. Results are presented as group data for the first finishers (A: speed 9.7±0.7 mph) and last finishers (B: speed 7.6±0.8 mph). Changes in plasma [Pr] and ions were used to estimate the losses of ions from the plasma and extracellular fluid (ECF) compartments. Significant increases in plasma [Pr] and Hct, and no change or decreases in plasma ions indicated an 8.5±5.8% reduction (both groups) in plasma and ECF volumes (about 2.4 L and 10 L respectively) and losses of Na^+, K^+, Cl^-, and Ca^{++}:

CALCULATED ION LOSSES FROM THE PLASMA and ECF (mmoles)

	Na^+	Cl^-	K^+	Ca^{++}
GROUP A Plasma	314	313	17	3.5
ECF	1275	1283	69	14.2
GROUP B Plasma	236	293	12	3.5
ECF	958	1190	49	14.2

In conclusion, the pronounced losses of fluid and ions may result in an impaired ability to perform. Current supplements are inadequate to maintain plasma fluid and ions at levels for optimizing performance. Quantification of muscle and whole body losses are required to determine optimal fluid and ion supplementation protocols. Supported by the Equine Research Centre and NSERC of Canada.

47.14

WHY ARE LEFT ATRIAL PRESSURES HIGH IN EXERCISING HORSES? B. L. Smith, J. H. Jones, J. R. Pascoe, W. S. Tyler and W. P. Thomas. Departments of Physiological Sciences, Surgery, Anatomy and Medicine, School of Veterinary Medicine, University of California, Davis, CA 95616.

The maximal specific cardiac output of the 500 kg Thoroughbred race horse (>750 ml min^{-1} kg^{-1}) is high for a mammal of its size, and is achieved with a heart rate exceeding 210 min^{-1} and a stroke volume of approximately 1.5 ℓ. In conjunction with this high specific cardiac output horses have unusually high mean pulmonary arterial (>120 torr) and systemic arterial (>240 torr) pressures during maximal aerobic exercise. We have recently reported that mean left atrial (LA) pressure in the exercising horse exceeds 70 torr (Jones *et al.*, *FASEB J.* 6:A2020, 1992), and we postulate that this may be related to the nearly ubiquitous occurrence of exercise-induced pulmonary hemorrhage in these animals. These high LA pressures could be required for ventricular filling because of low compliance of the left ventricle (C_{LV}), or they might be necessary to overcome high resistance of the mitral valve (R_{MV}), as mean flow through the mitral valve during ventricular filling (<0.15 s) exceeds 10 ℓ s^{-1}. To evaluate the contributions of C_{LV} and R_{MV} to raising LA pressure during exercise, we measured static compliance curves on flaccid Ca-blocked horse hearts immediately *post-mortem*, and measured pressure-flow curves across orifice plates of the same size as equine mitral valves (as determined by *in vivo* echocardiography) and across the mitral valves in cannulated *post-mortem* horse hearts. The results suggest that both C_{LV} and R_{MV} contribute significantly to elevating left atrial pressure during exercise in the horse. Supported by Grayson-Jockey Club Research Foundation, University of California Davis Equine Research Laboratory, California Satellite Wagering Research Fund, and Oak Tree Racing Foundation.

47.15

ORIGIN OF AIRWAY BLOOD IN EXERCISE-INDUCED PULMONARY HEMORRHAGE IN RACE HORSES. J. H. Jones, W. S. Tyler, J. R. Pascoe, B. L. Smith and E. K. Birks. Departments of Physiological Sciences, Anatomy and Surgery, School of Veterinary Medicine, University of California, Davis.

Although pulmonary hemorrhage is exceedingly rare among mammals, almost all race horses experience exercise-induced pulmonary hemorrhage (EIPH) when running. The etiology of this disease is not known, nor is it known if the blood that enters the airways originates from the systemic (bronchial) circulation, the pulmonary circulation, or both. To determine which vascular bed(s) is involved in EIPH we injected differently colored microspheres of 5 μm, 10 μm and 15 μm diameters into the pulmonary (via jugular vein) and/or systemic (via left atrium) circulations of Thoroughbred horses as they ran on a treadmill at speeds of 13-15 m s^{-1}, or as the horse stood quietly (control). Reference blood samples drawn simultaneously from the carotid and pulmonary arteries indicated that only 5 μm diameter spheres passed through the capillary beds and were recirculated. The horses were killed after they ran, their lungs were lavaged with 40-60 ℓ of saline, and the lavage fluid was centrifuged and chemically digested to allow microscopic examination for microspheres in the airway lavage fluid. No spheres were recovered from the control horse nor one of the horses that ran on the treadmill (at 13 m s^{-1}). In two horses that ran at 14-15 m s^{-1} 5 μm, 10 μm and 15 μm diameter spheres from only the pulmonary circulation were present in the lavage fluid. These results suggest that the pre-capillary pulmonary circulation plays a significant role in equine EIPH. Supported by Grayson-Jockey Club Research Foundation and UC Davis Equine Research Laboratory, California Satellite Wagering Research Fund, and Oak Tree Racing Foundation.

47.16

IS MAXIMAL EXERCISE LIMITED BY THE STRENGTH OF CAPILLARIES IN THE LUNG OR GILL? John B. West and Odile Mathieu-Costello. UCSD, La Jolla, CA 92093-0623.

The lung blood-gas (or gill blood-water) barrier has two (or more) functions. One is to transfer O_2 and CO_2 by passive diffusion, which requires it to be extremely thin. Another is to be the wall of the lung or gill capillary, which requires it to be strong enough to withstand high stresses when the capillary pressure is raised. The capillaries of rabbit lungs rupture when capillary pressure exceeds ≈ 40 mmHg. Fishes have a special problem because the heart has only one chamber and therefore the hydrostatic pressure in the gills exceeds that in the dorsal aorta. For example, the mean dorsal aortic pressure in athletic fishes such as the albacore tuna, *Thunnus alalunga*, is as high as 79 mmHg, and the pressure must be higher in the gill capillaries. However $\dot{V}O_{2max}$ is smaller, e.g. ≈ 24 ml/(min.kg) in skipjack tuna compared to ≈ 97 in an athletic mammal of same body mass (spring hare). Thus, the gill membrane can afford to be thicker and therefore stronger. In mammals where the higher $\dot{V}O_{2max}$ necessitates a much thinner blood-gas barrier, a single chambered heart would require the pulmonary capillary pressure to be so high that capillaries would rupture during exercise. Therefore all mammals have a double-chambered heart. Even so, it appears that the human blood-gas barrier is not thin enough to prevent diffusion-limited O_2 uptake in elite athletes, nor strong enough to have a large safety factor for stress failure during maximal exercise. An extreme situation is seen in thoroughbred horses, where the very high $\dot{V}O_{2max}$ (up to 180 ml/(min.kg) require a thin blood-gas barrier, but the extremely high cardiac outputs > 750 ml/(min.kg) require mean left atrial pressures of up to 70 mmHg to fill the left ventricle. Pulmonary artery pressures are as high as 120 mmHg (mean) and capillary pressures must approach 100 mmHg. As a consequence, essentially all thoroughbreds bleed into their lungs during racing. The bioengineering dilemma of requiring the blood-gas barrier to be extremely thin to allow adequate O_2 transfer, yet extremely strong to withstand the high capillary pressures associated with very large cardiac outputs, is a hitherto overlooked factor limiting maximal exercise.

47.17

CLOSE REGULATION OF PERFUSION TO METABOLISM BETWEEN FORELEGS AND HINDLEGS IN THE EXERCISING HORSE. P.D. Wagner, G. Nyman, M. Björk, P. Funkquist, B. Essén-Gustavsson, A. Lindholm and S.G.B. Persson. Dept. of Med., Univ. of Calif. San Diego, La Jolla, CA 92093-0623 and Swedish Univ. of Agricultural Sciences, Uppsala, Sweden

We compared gas exchange and acid-base status in iliac venous (IV) and pulmonary artery (PA) blood of horses at rest and during exercise. This was done: 1) to infer comparisons of foreleg versus hindleg perfusion/metabolism balance, and 2) to determine whether the easier and more informative pulmonary artery catheter would reflect muscle venous blood during exercise. Physiologically insignificant (yet statistically significant) differences were found at rest and light (≤40% max) exercise in PO_2, O_2 saturation, PCO_2 and blood temperature, but these disappeared above 80% of $\dot{V}O_{2max}$. In contrast, due to higher IV [lactate] at ≥80% of max, IVpH was lower and base excess more negative: Data at ≥80% of $\dot{V}O_{2max}$:

	PO_2 Torr	PCO_2 Torr	pH	O_2 Sat %	Temp °C	Hb g dl^{-1}	HCRIT %	[Lactate] mmL^{-1}	Base Excess meqL^{-1}
IV:	14.1	110.8	7.075	12.1	41.0	18.6	54.9	14.9	- 7.0
PA:	14.5	111.3	7.081	12.4	41.0	18.7	55.0	13.3	- 6.3
p :	NS	NS	.02	NS	NS	NS	NS	.005	.001

While gas exchange parameters change little from 80 to 100% of $\dot{V}O_{2max}$, those related to acid-base balance change rapidly due to rapid rise in blood lactate. Most, if not all, of the IV-PA acid-base differences can be ascribed to the small but finite time delay from IV to PA. We conclude that over the entire exercise range, forelimbs and hindlimbs are in remarkable perfusion/metabolism balance and that pulmonary artery sampling accesses blood representative of maximally exercising muscle. Supported by NIH HL 17731 and TRDRP 1RT 227.

47.18

EFFICIENT EXERCISE: AN ADAPTATION TO HIGH ALTITUDE? LLAMAS AND PONIES COMPARED. P.L. Entin* and C. Richard Taylor. CFS, Harvard University, Old Causeway Road, Bedford, MA 01730.

Indians living in the Andes have adapted to the oxygen-sparse air of high altitude by exercising economically. They can run faster on a treadmill and work harder on a bicycle while consuming oxygen at the same rate as their lowland compatriots. We asked if their domestic animal, the llama, has the same adaptation. The llama has many adaptations to a hypoxic environment in its genome (e.g., high oxygen affinity hemoglobin) and it seemed possible that exercise efficiency might be included in its repertoire. To test this hypothesis, we compared the llama with the pony, a lowland animal that lacks these adaptations. We measured steady state oxygen consumption ($\dot{V}O_2$) of three llamas and three ponies as they walked on a treadmill. The $\dot{V}O_2$ of the llamas was nearly identical to that of the ponies over their range of walking speeds, 0.2 to 1.5 m/sec. The cost of transport, the oxygen cost of moving a kg of body mass one meter, reached a minimum of 0.12 ± 0.010 ml O_2/kg·m in the llama and 0.11 ± 0.006 ml O_2/kg·m in the pony at about 1 m/sec. We also compared their efficiency in working against gravity, i.e., work rate over total metabolic rate times 100. In both species work efficiency while walking up a 6° incline increased with speed from 9 to 18%. We concluded that efficient exercise is not among the llama's adaptations to high altitude. Supported by NIH Grant 5 R01 AR18140-16 and NSF Grant DCB8918371.

47.19

ENHANCED DYNAMIC RESPONSE OF AVIAN INTRAPULMONARY CHEMORECEPTOR (IPC) DISCHARGE DURING VENOUS CO_2 LOADING. S.C. Hempleman and D.E. Bebout. Division of Physiology, U.C. San Diego, La Jolla, CA 92093.

We studied the CO_2 step responses of 11 single unit IPC in the perfused, unidirectionally ventilated left lungs of 5 anesthetized pekin ducks. Right lungs were independently ventilated with CO_2 and air to produce, in turn, normal and elevated $PvCO_2$ (41±4.6 and 76.8±6.2 Torr). Left lung ventilatory flow of 0.02 $FICO_2$ in air was adjusted to give the same IPC discharge rate under normal and CO_2-load conditions (thus matching $PECO_2$ levels, Hempleman et al., 1986). $FICO_2$ steps, 0.02-0.06, 11s period, were given and dynamic discharge oscillations were quantitated with stimulus cycle triggered histograms. Average discharge frequency oscillation amplitudes (max-min) were the same under normal and CO_2 load conditions (21±4 and 25±5 sec^{-1}), but the frequency ratio of (max-min)/mean, reflecting the over and undershoot relative to mean discharge rate, was 49±14 % greater during CO_2 load. The results show that increased convection and diffusion in the lung during venous CO_2 load increases the dynamic character of IPC discharge, which may affect ventilatory control during exercise. Supported by NIH HL17731 and HL02071.

47.20

EFFECTS OF CHRONIC HYPERCAPNEA ON AVIAN INTRAPULMONARY CHEMORECEPTORS. D. E. Bebout and S. C. Hempleman. Division of Physiology, 0623, Department and School of Medicine, University of California, San Diego, 9500 Gilman Drive, La Jolla, Ca 92093-0623.

To investigate the effects of chronic hypercapnea on the stimulus-response characteristics of individual intrapulmonary chemoreceptors (IPC), we recorded single unit vagal activity from 34 IPC in 6 anesthetized, unidirectionally ventilated Pekin ducks after 12 d acclimatization to 7.5 % inspired CO_2. For comparison, we recorded vagal discharge from another 23 IPC in 9 control ducks of equal age. Based on the hypothesis that the CO_2 sensitivity of IPC is mediated by H^+ from CO_2 hydration rather than CO_2 directly, we predicted that IPC discharge frequency for a given PCO_2 would be greater after chronic hypercapnea, because of $HCO3^-$ retention and lower [H^+] for a given PCO_2. After CO_2 acclimatization, the PCO_2 associated with a blood pH of 7.40 increased to 64 Torr in the acclimatized birds, compared to 38 Torr for the controls, indicating significant $HCO3^-$ retention after CO_2 acclimatization. Individual IPC logarithmic stimulus-response curves were described by mean intercepts of 81.1±4.0 and 48.4±3.6 impulses/s and mean slopes of -19.0±1.0 and -12.0±1.1 impulses/(s·lnPCO_2) in the CO_2 acclimatized and control birds, respectively. Both the mean intercept and mean slope were significantly greater in the acclimatized birds ($P < 0.01$), with the larger intercept indicating a greater discharge frequency for a given PCO_2. We conclude that the IPC sensitivity to CO_2 is mediated by H^+ from CO_2 hydration and not by CO_2 directly. The increased slope may indicate less buffering capacity in the chemosensitive environment in the acclimatized birds. (Supported by NIH HL07212, NIH HL17731 and Amer. Lung Association, Calif.).

47.21

SEASONAL CHANGES IN MUSCLES OF BLUE-WINGED TEAL. David K. Saunders Kansas State University, Manhattan, KS 66506.

Muscles of Blue-winged teal (BWT) undergo seasonal (migration, molt) changes in weight and biochemical properties that may be regulated by mechanisms other than use-disuse. I observed activity of BWT at a wildlife reserve from the end of Spring migration (May 1) through the molt, to the start of Fall migration (Aug.) of 1990. At five times during that interval I collected 5 birds and measured muscle weights (MW) and the activities of citrate synthase (CS, an index of aerobic capacity) and lactate dehydrogenase (LDH, an index of anaerobic capacity). Leg MW decreased throughout the molt (July 1 - Aug 1), a period when birds were flightless and dependent upon the legs for locomotion (fig 1). CS paralleled MW except in heart (fig 2). LDH increased in heart and leg muscles during the molt (fig 3). Flight and heart MW decreased during the molt but began to increase before the onset of extensive flight activity at the end of the molt (fig 1). Some of these changes in muscle properties do not appear to occur in response to changes in muscle activity.

Figure 1. Muscle Weights

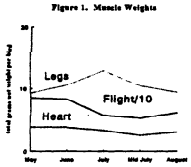


Figure 2. Citrate Synthase

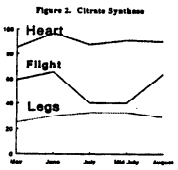
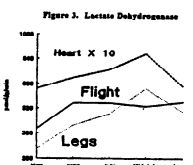


Figure 3. Lactate Dehydrogenase



48.1

GUTTURAL POUCH AND NASOPHARYNGEAL PRESSURES IN THE HORSE DURING EXERCISE. R.S. Rehder* and A. Dobson. College of Veterinary Medicine, Cornell University, Ithaca, N Y 14853.

The guttural pouches, bilateral diverticula of the Eustachian tubes each holding ~0.3 l air, have no established function. An endoscope was used to observe the Eustachian tube opening and to place matched teflon pressure catheters in the pouches and pharynx. Many activities, swallowing (which opens the tubes), snorting or head movements, altered pouch pressures. During treadmill exercise, pressure changes in both pouches were similar and in phase, but were out of phase with, and about half the amplitude of those in the pharynx. Pouch pressure exceeded pharyngeal pressure at the end of expiration and during most of inspiration. In the standing horse, the septum separating the pouches had a compliance twice the rest of a pouch wall (mainly the compliance between the pouch and pharynx). Leakage after air injection precluded pouch pressures above 2 cmH_2O. Much higher positive pressures were developed during exercise, possibly due to muscular activity compressing the walls and decreasing their compliance, combined with active control of the Eustachian tube. The results suggest that ventilation of the pouches is infrequent and not exclusively tied to breathing. Guttural pouches permit control of the shape of the nasopharyngeal roof.

(Supported by C.N.P.Q., Travers Fund and N.Y.H.B.P.A.)

48.2

MAXIMAL EXPIRATORY FLOW AND VENTILATORY RESERVE AT MAXIMAL EXERCISE. T.G. Babb and J.R. Rodarte. Baylor College of Medicine, Houston, TX 77030.

To investigate the impact of maximal expiratory airflow on ventilatory reserve during maximal exercise, we compared maximal exercise ventilation ($\dot{V}_E$max) to estimates of maximal ventilatory capacity in 13 subjects with normal pulmonary function and 23 subjects with mild to severe airflow limitation (FEV_1/FVC=68 to 39%). Maximal ventilatory capacity was estimated using the maximal voluntary ventilation (MVV) and a calculated ventilatory maximum ($\dot{V}_E max_{cal}$), which was determined from each subject's maximal expiratory flow-volume curve and individual estimates of tidal volume, inspiratory duty cycle, and lung volume. All subjects performed graded cycle ergometry to exhaustion. $\dot{V}_E$max was correlated with MVV and $\dot{V}_E max_{cal}$ (r=0.70 and 0.69, respectively, p<0.0001); however, the $\dot{V}_E$max/MVV% indicated a larger ventilatory reserve than $\dot{V}_E$max/$\dot{V}_E max_{cal}$% (p<0.05). The difference between $\dot{V}_E$max/MVV% and $\dot{V}_E$max/$\dot{V}_E max_{cal}$% was significant for subjects with mild, moderate, or severe airflow limitation (p<0.05), whereas it was not significant in subjects with normal maximal flows. These data suggest that ventilatory reserve is smaller when estimated from the maximal expiratory flow-volume curve than from the MVV, especially in subjects with mild-to-moderate airflow limitation. (Supported by AHA/Texas Affiliate, ALA/San Jacinto Area, and HL-07222).

48.3

EXPIRATORY FLOW LIMITATION AND REGULATION OF END-EXPIRATORY LUNG VOLUME DURING EXERCISE. J.R. Rodarte, †R. Pellegrino*, ††V. Brusasco, and T.G. Babb. Baylor College of Medicine, Houston, TX 77030, †Ospedale A. Carle, Cuneo, Italy, and ††Universita di Genova, Genova, Italy.

To investigate the impact of expiratory flow limitation (FL) on breathing pattern and end-expiratory lung volume (EELV), we studied nine volunteers (29-62 yr), six healthy and three with mild-to-moderate airflow obstruction (67-71% of predicted FEV_1), during exercise. Six subjects showed evidence of FL, i.e., tidal expiratory flow impinging on maximal forced expiratory flow, at one or more exercise levels. Whenever an expiratory threshold load was imposed, mean expiratory flow (V_T/T_E) decreased (p<.02) associated with an increased expiratory time (T_E) (p<.05). During non-FL conditions, T_E increased less than expiratory flow decreased and EELV tended to increase. In contrast, during FL, T_E increased more than expiratory flow decreased, subjects did not achieve maximal expiratory flow until a lower volume, and EELV decreased (p<.001). Under both FL and non-FL conditions, unloading reversed the changes associated with loading. These data indicate that the increase in EELV during exercise is linked to the occurrence of FL. We suggest that compression of airways downstream from the flow-limiting segment may elicit reflexes which terminate expiration, thus increasing EELV. (Supported by AHA/Texas Affiliate and ALA/San Jacinto Area).

48.4

DO ASTHMATICS DEVELOP BRONCHOCONSTRICTION DURING EXERCISE? K.C. Beck, B.A. Staats, and P.D. Scanlon. Mayo Clinic and Mayo Foundation, Rochester, MN 55905.

In exercise-induced asthma (EIA) bronchoconstriction develops after exercise. Some asthmatics report the onset of symptoms during exercise. **PROTOCOL:** Six asthmatics exercised (cycle ergometer) on 3 occasions breathing dry, room temperature air. Spirometry was performed at regular intervals during and after exercise. On day 1 an incremental (INC) exercise test was performed to determine VO2max. On day 2, constant load (CL) exercise at 50% of VO2max was performed for 36 min. On day 3, an interval (INT) protocol was followed: 60% of VO2max for 6 min followed by 40% VO2max for 6 min, repeated for 3 cycles, 36 min total. **RESULTS** (Mean ± SD, % change from baseline). FEV1 during INC increased +3.8% ± 7.3 at maximum exercise and fell -36.6% ± 15.8 within 10 min following exercise. FEV1 during INT was +1.0% ± 13.5 during the first 60% VO2max load, but fell -14.8% ± 13.1 after 6 min at 40% VO2max. Upon returning to 60% VO2max, FEV1 increased (-5.3% ± 14.07), and during subsequent decreases to 40% VO2max, FEV1 fell (-16.2% ± 9.94). FEV1 fell following INT to -32.4% ± 8.7. During CL, FEV1 fell starting at 15 min (-9.0% ± 6.7) and remained stable until 36 min, then fell -28.1% ± 10.7 within 10 min after exercise. **CONCLUSION:** Consistent with concept that bronchoconstriction occurs only after exercise, FEV1 improved during the INC protocol, but fell afterwards. In contrast, FEV1 fell during both prolonged CL exercise and INT exercise. Variable FEV1 during exercise may reflect variations in balance of bronchodilating and bronchoconstricting influences. Supported in part by American Lung Association of Minnesota.

48.5

ABNORMALITIES IN EXERCISE GAS EXCHANGE AS AIRWAY OBSTRUCTION INCREASES. **R. Carter, B. Nicotra, W. Blevins, and D. Holiday. The University of Texas Health Center at Tyler, Tyler, Texas.**

The purpose of this study was to evaluate exercise capacity and gas exchange in a large cohort of patients with COPD as compared to non-obstructed individuals. A total of 521 people completed lung function and symptom limited graded maximal exercise testing (478 obstructed and 31 non-obstructed individuals) on a cycle ergometer using open circuit gas collection. In concordance with previous studies, our patients presented with reduced ventilatory and work capacity, increased dyspnea and altered gas exchange. Smoking history correlated weakly, yet significantly, with reductions in the FEV_1 (r = -.18, p < .0001). Spirometric measures (FVC, FEV_1, FEF, PEF) of pulmonary function declined with increasing severity of COPD (p < .0001). Peak oxygen uptake (VO_{2max}) decreased as airway obstruction (FEV_1) became more severe (r = .69; p < .0001) as did VE, VCO_2, RR, VT and O_2P (p's < .001 to .0001) independent of age-related declines. VE_{max} decreased from approximately 58 to 34 l/min as airway obstruction increased. This represented an increase in the % predicted VE_{max} from 59 to 88% and a reduction in ventilatory reserve from 42 to 6 l/min. Peak HR responses were, on the average, greater than 90% of predicted with a trend downward from 96 to 90% as airway obstruction increased (p < .05). The presence of significant arterial oxygen desaturation was noted in 93 of 238 (39%) patients with severe obstruction. When this group was analyzed separately, significant decreases in FEV_1 (p < .03), FEV_1/FVC (p < .0002) and resting SaO_2 (p < .0001) (93.4+/-1.8 vs 87.9 +/-2.72) were found. No difference in maximal VE, VO_2, VCO_2, VT, RR, HR or O_2 pulse was noted between those individuals who desaturated compared to those who did not (p > .05). Similar results were obtained for those with a 5% or greater decline in SaO_2. These data confirm that exercise performance diminishes as airway obstruction progresses. Moderate changes in HR and O_2 pulse suggest a classical detraining response or a reduction in cardiac output secondary to altered lung perfusion or mechanical alteration. Yet, the major decrease in physical work capacity can be attributed to the failure of ventilation to match the metabolic requirements for work. As a group, there appears to be little difference between those individuals with severe airway obstruction who desaturate versus those who do not with respect to peak work performance.

48.6

EFFECTS OF THORACIC BLOOD VOLUME SHIFTS ON VITAL CAPACITY. Joseph A. O'Kroy and J. Richard Coast. Texas A&M Univ., College Station, Tx. 77843

Vital capacity (VC) has been shown to decrease following heavy exercise with increased thoracic blood volume (TBV) being implicated as one of many possible causes. We used lower body positive and negative pressures (LBPP,+30 mmHg; LBNP,-30 mmHg) to increase or decrease TBV, respectively. Subjects were fitted into a box and sealed around the hips at the level of the greater trochanter. LBPP was administered with the subjects seated and their back supported while LBNP was administered in the supine position. Spirometry was performed with a Collins 13.5 liter water filled spirometer while in these positions prior to pressure application, during pressure application (after 5 min) and after cessation of pressure application (after 5 min). Analysis showed a significant increase in forced vital capacity (FVC; 0.212L, 4.6%; p=0.0004) and forced expiratory volume in one sec ($FEV_{1.0}$; 0.12L, 3.49%; p=0.029) with LBNP and a decrease in FVC (0.169L, 3.59%; p=0.0002) with LBPP. $FEV_{1.0}$ was not reduced with LBPP. This suggests that increases in TBV may be a significant factor in the reduction of VC seen with heavy exercise.

48.7

RESPIRATORY MUSCLE FATIGUE AT HIGH ALTITUDE. F. Cibella*, S. Romano*, IFR CNR, Palermo, Italy; G. Cuttitta*, ISTSAF, CNR, Palermo, Italy; B. Kayser*, Dept. Physiology CMU, Geneva, Switzerland; M. Narici and F. Saibene*, ITBA, CNR, Milano, Italy

In order to study factors limiting exhaustive exercise at high altitude, four healthy males (age 34.2±0.96 yr, weight 76±17 kg, height 1.76±0.05 m) exercised until exhaustion at 75% VO2 max, (225.0±57.4 W at sea level, SL, and 172.5±28.7 W at high altitude, HA, after one month at 5050 m). Exhaustion time at HA decreased by 51.7%±15.0%. Throughout the exercise VE increased comparatively more at HA than at SL reaching 169±7 l/min (BTPS) at HA and 98±6 l/min at SL. In both circumstances just before the exhaustion the respiratory rate suddenly rose to a higher value, attaining respectively 72±10 breaths/min at HA and 51±16 breaths/min at SL. Mean inspiratory esophageal pressure decreased towards exhaustion at HA while stayed constant or increased slightly at SL. Mean inspiratory gastric pressure became negative (-4.4±3.8 cmH20) at HA whereas stayed positive at SL (+0.1±1.3 cmH20). As a consequence mean transdiaphragmatic pressure (PDI) declined at exhaustion at HA. Integrated EMG of the diaphragm (iEMGDI) progressively increased during the exercise at HA, but remained constant at SL. The iEMG of the *vastus lateralis* did not change either at SL or at HA. From these data it appears that the contribution of the diaphragm to the work necessary to sustain such high levels of VE at HA is decreased. The decrease in PDI coupled to the progressive increase in iEMGDI may be the result of diaphragm fatigue occuring towards the end of the exercise at HA. On the contrary no objective signs of fatigue have been detected on the limb muscles.

48.8

DOES ABDOMINAL MUSCLE FATIGUE AFFECT THE RESPONSE TO AN EXPIRATORY THRESHOLD LOAD (ETL)? **Frank J. Cerny, Margo Wiedrich*. SUNY @ Buffalo, Buffalo, NY 14214**

The abdominal muscles are the primary muscles of expiration. The purpose of this study was to determine the effect of exercise-induced abdominal muscle fatigue on the ventilatory responses to an expiratory load. Fatigue was induced by performing partial sit-ups (crunches) @ .5 Hz, with 10 sec rests when needed, until the subject could not continue. Ventilatory measures were made during quiet breathing and 3 minute ETL of 15 cm H_2O, before and immediately after fatigue. Minute ventilation and its components, tidal volume and breathing frequency and inspiratory, expiratory, and total cycle durations were measured with a pneumotachometer on the inspiratory side of a one-way breathing valve. Fatigue was induced in 10 to 20 minutes. Minute ventilation, breathing frequency and the ratio of inspiratory duration to total cycle duration were greater, due to a shorter expiratory duration, during post-fatigue ETL compared to pre-fatigue. Tidal volume was unchanged. Abdominal muscle fatigue alters breathing pattern during ETL by changing expiratory timing.

48.9

HYPOXIC EFFECTS ON EXERCISE-INDUCED DIAPHRAGM FATIGUE. M.A.Babcock*, B.D.Johnson*, D.M. Griffin*, D.Pegelow*, O.E.Suman* and J.A. Dempsey. John Rankin Laboratory of Pulmonary Medicine, Univ. of Wisconsin, Madison, WI 53705

We examined the effects of breathing a hypoxic gas mixture during heavy endurance exercise on diaphragm fatigue. Eight male subjects gave informed consent and completed two exercise tests at 85% VO_2max, one in normoxia(N) and one in hypoxia (H) (.15 FiO_2, SaO_2 end exercise = 77.3% ı 1.46). Supramaximal bilateral phrenic nerve stimulation (BPNS) was used to determine the force output of the diaphragm at FRC pre- and post-exercise using 1 Hz twitches and tetanic stimulations at 10 Hz and 20 Hz. After N exercise a significant decrease in Pdi at 1 Hz(-22.1%,p<.001), and 10 Hz(-22.2%,p<.02) occurred. Pdi recovered at all levels by 60 m post-exercise. During the hypoxic exercise subjects had a increase in $\dot{V}_E$ (due to increased f_B) compared to the same time in N exercise. There was a decrease in exercise time during the hypoxia run (N 26.9 m vs H 18.5 m, p<0.002). A significant decrease in the Pdi at 1 Hz(-16.0%,p<.01) and 10 Hz(-15.6%,p<.04) occurred after H exercise. The Pdi at 1 Hz recovered after 90 m. In conclusion hypoxia resulted in the same amount of diaphragm fatigue as normoxic exercise but in a third less exercise time. We hypothesize that the effects of hypoxia may be due to both decreased O_2 transport and to increased ventilatory work. (Supported by ALA and NHLBI.)

48.10

HYPOXIC-EXERCISE EVOKES SHORT TERM POTENTIATION (STP) OF ABDOMINAL MUSCLE ACTIVITIES IN HUMANS. R. Fregosi, J. Skatrud and J. Dempsey. Univ. of Arizona, Tucson, AZ 85721 and Univ. of Wisconsin, Madison WI 53705.

The increase in ventilation (V_I) evoked by hypoxia persists for several seconds after the stimulus is removed. This phenomenon, known as STP, is most pronounced when hypoxia is combined with mild exercise (Fregosi, R.F., J. Appl. Physiol. 71:892, 1991). Our purpose was to determine if hypoxic exercise evokes STP of *expiratory* motor activity. V_I, end-tidal CO_2 and O_2 and external oblique abdominal EMG activities were recorded in six healthy subjects (5 M, 1 F). They exercised on a bike at 90 W while breathing O_2 for 1.5 min. ("control"), followed by 1.5 min. of hypoxia (10 % O_2, balance N_2). Hypoxia was terminated abruptly by changing the inspirate back to O_2 as exercise continued. Hyperventilation persisted for 9 ± 3 (SE) *breaths* (range, 3-20) following the onset of O_2 administration; abdominal activity, which was present in all subjects in hypoxic exercise, remained elevated for 8 ± 4 *breaths* (range, 1-25). Separate experiments showed that abdominal muscle activity did not change during *normoxic* exercise at 90 W, but increased at 180 W to 98 ± 26 % of the level observed in *hypoxic exercise* at 90 W (P < 0.05 vs. rest). In summary: 1) STP of abdominal muscle activity is evoked by hypoxic exercise, but the inter-subject variability is marked; 2) moderately intense normoxic exercise increases abdominal motor activity significantly. Supported by NHLBI.

48.11

INFLUENCE OF MENTAL STRESS ON HYPERVENTILATION DURING INCREMENTAL EXERCISE. E. Onda, N. Hayashi*, Y. Nakamura, and I. Muraoka. Waseda Univ., Tokorozawa, Saitama, 359 JAPAN

The purpose of this study was to investigate the influence of mental stress on ventilatory kinetics during incremental exercise. After signing an informed consent, five healthy male volunteers performed two bouts of incremental exercises. One was under normal condition (N). Another was under stressful condition (S), which consisted of blindfold, hearing noise, and mental arithmetics. In both conditions, blood sample was taken at the same time during final phase before exhaustion, at which minute ventilation ($\dot{V}_E$) of N and S was also compared with each other. There was considerable interindividual variety in the effect of stressful tasks on hormonal and ventilatory responses. Of subjects, three showed eminent increase of both plasma epinephrine and adrenocorticotropic hormone (ACTH) levels in S comparing with N. In these subjects, moreover, S induced an earlier hyperventilation during incremental exercise than N. As the results, the difference between the $\dot{V}_E$ values of N and S was highly correlated to those of both epinephrine and ACTH (r=0.937, p<0.05 and r=0.946, p<0.05, respectively). These results suggest the possibility that hyperventilation during incremental exercise referred to one of general responses to psycho-physiological stresses.

48.12

WHEN DOES AN INSPIRATORY LOAD LIMIT MAXIMUM OXYGEN UPTAKE IN HUMANS? R.G. Thomas, S.L. Lindstedt and S.A. Rasmussen. Northern Arizona University, Flagstaff, AZ 86011.

We measured the V_{O2}max and peak inspiratory flow ($V_I$max) of highly trained (V_{O2}max > 65 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$) and untrained (<45 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$) male subjects on a cycle ergometer while they were breathing through an inspiratory orifice (IO). By plotting both the pressure at the mouth as well as $V_I$max, we were able to construct inspiratory muscle (IM) pressure-flow curves for each subject. Pressure-flow curves are analogous to the Hill force-velocity curves familiar for skeletal muscle, the products of both plots are power. Despite the highly significant difference in V_{O2}max between the two groups of subjects, there was no difference in their IM pressure-flow curves or respiratory muscle maximal instantaneous power output. When subjects worked at their peak aerobic workloads with IO in place, V_{O2}peak in the trained subjects dropped when IO <130mm^2 and in the untrained subjects when IO <75mm^2. A single regression describes VO_2peak as a function of orifice area in both groups. These results suggest that inspiratory airway resistance and power of the inspiratory muscles do not co-vary with V_{O2}max in humans, rather these may be matched to the maximum (species-specific) aerobic performance in humans. Perhaps only those structures with the greatest phenotypic plasticity will be linked to demand (symmorphosis), those with minimal plasticity must be built to accommodate changes in the malleable structures. (NIH RO1HL41986; AHA, Flinn Foundation Fellowship)

48.13

ALTERATIONS IN THE VENTILATORY RESPONSES TO INCREMENTAL CYCLING FOLLOWING A REDUCTION IN MUSCLE GLYCOGEN CONTENT. Donald A. Schneider, and Stephen E. Phillips*. Northeastern University, Boston, MA 02115

Nine untrained female subjects were studied during incremental cycling performed in the normal glycogen state (NG) and under conditions of reduced muscle glycogen content (RG). Absolute oxygen uptake measured at the ventilatory threshold (Tvent) increased by 32%, while oxygen uptake determined at the respiratory compensation threshold (RCT) was increased by about 5% during conditions of RG compared to the NG state. The ventilatory threshold was detected using a computerized V-slope method that minimized the residual sum of squares of the breakpoint, whereas the RCT was determined as the first point of departure from linearity of minute ventilation plotted as a function of carbon dioxide production. We have demonstrated that muscle glycogen reduction resulted in a significant delay in the onset of both the ventilatory and respiratory compensation thresholds. These data suggest that (1) increased fat oxidation and a slower rate of glycolysis contributed to the delay in the onset of these thresholds and (2) that muscle tissue hypoxia is not solely responsible for lactate production and the onset of the blood lactate and/or ventilatory thresholds.

48.14

EFFECTS OF AGEING AND FITNESS ON THE VENTILATORY RESPONSE TO CO_2 IN HYPEROXIA AND HYPOXIA IN HUMANS. M.J. Poulin*, D.A. Cunningham, W.D. Smith*, and J.M. Kowalchuk. Univ. of Western Ontario (Kinesiology, Physiology, Lawson Research Institute), London, Ontario N6A 3K7.

Although earlier studies (Kronenberg & Drage 1973, J. Clin. Invest., 52:1812-1819) found the ventilatory response to hypoxia and hypercapnia to be decreased with advancing age, more recent studies (Ahmed et al. 1991, Respir. Physiol. 83:343-352; Rubin et al. 1982, J. Gerontol. 37(3):306-312) have found little or no ageing differences in these responses. This study examined the ventilatory response to CO_2 in acute hypoxia ($P_{ET}O_2$= 50 Torr) and in hyperoxia ($P_{ET}O_2$=500 Torr) in groups of young active (YA, n=7, 28.3±2.7 (S.E.) yrs, $\dot{V}O_2max$=48.7±3.8 ml·kg^{-1}·min^{-1}), elderly trained (ET, n=6, 76.3±1.5, 33.3±3.3), and elderly untrained (EU, n=5, 75.8±1.9, 20.2±0.6) subjects. A computer-controlled dynamic end-tidal forcing system was used to control inspired gas breath-by-breath. Two protocols were used; I, $P_{ET}CO_2$ was held near eucapnia (1-2 Torr above rest) and II, $P_{ET}CO_2$ was held 7-8 Torr above rest. $P_{ET}O_2$ was held at 100 Torr throughout except for 2-two minute periods at 500 Torr and 50 Torr. In Eucapnia, no differences were found in ventilation ($\dot{V}_E$, ℓ·min^{-1}) in response to acute hypoxia and hyperoxia. In hypercapnia while no differences were found for $\dot{V}_E$ in response to hyperoxia, $\dot{V}_E$ was significantly lower in ET (38.5±2.5) and EU (36.5±3.6) compared to YA (52.2±3.2) in response to acute hypoxia. In hypoxia, there were no differences between groups in O_2 saturation. We conclude that, compared to YA, $\dot{V}_E$ was lower in ET and EU in response to hypoxia, but not hyperoxia, in moderate hypercapnia, suggesting a decreased peripheral CO_2 sensitivity in the elderly.

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48.15

EFFECTS OF AGEING ON THE SLOPE AND THE CO_2 THRESHOLD OF THE VENTILATORY-CO_2 RESPONSE CURVES IN HYPEROXIA AND HYPOXIA. D.A. Cunningham, M.J. Poulin*, W.D. Smith*, and J.M. Kowalchuk. Univ. of Western Ontario (Faculty of Kinesiology, Dept. of Physiology, and the Lawson Research Institute), London, Ont. N6A 3K7.

Conflicting findings have been reported regarding the effects of fitness and ageing on the human respiratory control system and its response to both hypoxia and hypercapnia. This study examined the response curve slope (S) and the CO_2 threshold (B) of the ventilation ($\dot{V}_E$)-CO_2 response curves in acute hypoxia ($P_{ET}O_2$= 50 Torr) and in hyperoxia ($P_{ET}O_2$=500 Torr) in groups of young active (YA, n=7, 28.3±2.7 (S.E.) yrs, $\dot{V}O_2max$=48.7±3.8 ml·kg^{-1}·min^{-1}), elderly trained (ET, n=6, 76.3±1.5, 33.3±3.3), and elderly untrained (EU, n=5, 75.8±1.9, 20.2±0.6) subjects. The data were fit to the linear equation $\dot{V}_E$=S($P_{ET}CO_2$-B). A computer-controlled dynamic end-tidal forcing system was used to control inspired gas breath-by-breath. Two protocols were used; I, $P_{ET}CO_2$ was held near eucapnia (1-2 Torr above rest) and II, $P_{ET}CO_2$ was held 7-8 Torr above rest. $P_{ET}O_2$ was held at 100 Torr throughout except for 2-two minute periods at 500 Torr and 50 Torr. In hyperoxia, B was lower for EU (28.3±1.2) compared to YA (34.8±1.8). In hypoxia, B was lower for EU (23.9±1.0) and ET (27.3±1.1) compared to YA (33.5±0.7). S (ℓ·min^{-1}·Torr^{-1}) in hypoxia (central + peripheral gains) was lower in ET (2.88±0.36) and EU (2.97±0.58) compared to YA (4.76±0.37) and there was no differences in S in hyperoxia (central gain). Thus there were no age or fitness differences in the gain of the central chemoreceptors (measured CO_2 sensitivity in hyperoxia) although the gain of the peripheral chemoreceptors (calculated CO_2 sensitivity in hypoxia) was lower for ET and EU. Also, the CO_2 threshold (B) was lower in the elderly groups.

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48.16

EXERCISE VENTILATION AND GAS EXCHANGE AFTER HEART AND LUNG DENERVATION IN HUMANS. G. Ferretti*, B. Grassi*, L. Xi*, M. Rieu*, M. Meyer, C. Marconi*, and P. Cerretelli. Depts of Physiology, Geneva, Switzerland and Paris, France; ITBA-CNR, Milano, Italy; Max Planck Inst. Exp. Med., Goettingen, Germany.

Heart and lung transplant recipients (HLTR) represent a unique opportunity to study in humans the mechanisms of ventilatory control during exercise. The study was conducted on 9 HLTR (age 31 ± 13 years, x ± SD; 16 ± 29 months post-transplant) and on two control groups of heart transplant recipients (HTR) (n=11) and healthy untrained subjects (C) (n=11). HLTR and HTR performed 2 to 6 exercise bouts (1 to 5 min) at 25 or 50W (about 50% of $\dot{V}O_2max$). C exercised at 50W (C1) or at 50% of their $\dot{V}O_2max$ (C2). Inspiratory ($\dot{V}I$) and expiratory ($\dot{V}E$) ventilation, tidal volume (VT), respiratory frequency (f), O_2 uptake ($\dot{V}O_2$) and CO_2 output ($\dot{V}CO_2$) were measured breath-by-breath. Phase I V response to exercise was evaluated as the mean changes of $\dot{V}I$, VT and f ($\Delta\dot{V}I$, ΔVT, Δf) during the first two breaths after exercise onset compared to rest. The half-time of the $\dot{V}E$, $\dot{V}O_2$ and $\dot{V}CO_2$ kinetics (t1/2on-) was determined (phase II). In HLTR $\Delta\dot{V}I$ (6.5±5.9 L/min) did not differ from that of C1 (7.3+4.2) and C2 (9.0±4.5), and was higher than that of HTR (3.3±4.1). In HLTR t1/2on- of $\dot{V}E$ (71±21 s), $\dot{V}O_2$ (48±13) and $\dot{V}CO_2$ (69±17) were similar to those of HTR (73±27; 50±11; 68±22), but slower than those of C1 (35±11; 27±7; 36±11) and C2 (48±18; 35±7; 48±12). In 3 HLTR the ventilatory pattern during 5 min exercises was similar to that of HTR and C1, whereas 4 HLTR presented slightly higher VT and lower f. At steady-state no difference in $\dot{V}E$ was observed between HLTR and HTR. It is concluded that: 1) The ventilatory and gas exchange response to exercise is substantially unaffected by lung denervation. 2) The normal phase I in HLTR indicates that cardiac and/or pulmonary inputs to the respiratory centers are not involved in its regulation, or that their role can be subserved by other control mechanisms.

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48.17

THE RELATIONSHIP OF AMMONIA TO EXERCISE-INDUCED HYPERPNEA. B.J. Cameron, M.L.Walsh, C.T.C. Kenny, R.H. Morton, and E.W. Banister. School of Kinesiology, Simon Fraser University, Burnaby, B.C. Canada V5A 1S6

Ammonia (NH_3) has been extensively studied as a ventilatory stimulant at rest in animals and humans. NH_3, which crosses the blood-brain barrier, may stimulate ventilation by direct neuroactive effects, or by conversion to glutamate, or GABA. In the present study, the relationship of ammonia and pulmonary ventilation (V_E) were compared during exercise in humans. Other mediators of ventilation were also examined, including hydrogen ion (H^+), potassium (K^+), norepinephrine (NE), and core temperature (T_C). Five males subjects completed ramp incremental exercise (RE) to exhaustion, or prolonged constant work rate exercise (PE) at 50% maximum work rate, in both a normal (N) and glycogen depleted (GD) condition. During RE, exercise duration was significantly reduced from 18.5 ± 0.4 to 17.5 ± 0.4 min in the GD, compared with the N condition. PE duration was reduced from 82.0 ± 8.0 to 33.4 ± 4.5 min in the GD, compared with the N condition. Glycogen depletion also resulted in a significantly higher V_E at an equivalent time point in both RE and PE. Hyperpnea was mediated by a greater breathing frequency in both RE and PE. The increase in V_E could be explained, by the the contribution of [K+], pH, [NE], and T_C, as well as the observed increase in [NH_3] in both ramp and prolonged exercise. However, throughout prolonged exercise in both control and *glycogen depleted* subjects, and during ramp exercise in glycogen depleted subjects, a relative alkalosis was observed. Therefore an increased [H^+] was not obligatory to the stimulation of ventilation. It was apparent that during exercise, factors other than [H^+] must contribute to ventilatory drive. It was concluded that (i) ammonia is a potential ventilatory stimulant during exercise in humans, (ii) the contribution is probably additive to other exercise-induced mediators of ventilation. Maintained hyperpnea in the absence of acidosis indicates that redundancy must exist in respiratory control during exercise. NH_3, which is both (i) neuroactive and (ii) contributes to central neurotransmitter metabolism, may also increase the sensitivity of the respiratory system to other exercise-induced ventilatory mediators.

48.18

EFFECT OF INHALED GAS AND HEAD-DOWN TILT ON VENTILATORY RESPONSES. C.C. Cline*, J.M. Lawler, J.A. O'Kroy (SPON: J.R. Coast). Texas A&M U, College Station, Tx. 77843

The mechanisms regulating ventilation (V_E) during exercise in humans are controversial. We examined the ventilatory responses to head-down tilt while inhaling one of four gas mixtures: 1)room air (R), 2)90% O_2 (O), 3) 90% O_2, 1.25% CO_2 (L), and 4) 90% O_2, 2.25% CO_2 (H). Ten subjects each participated in 8 tilt sessions (2 of each gas) which consisted of 11 mins of rest at 15 deg, a 90 sec -30 deg tilt, and 1 min recovery. Breath-by-breath measurements of V_E, $ETCO_2$, tidal volume (V_T) and breathing frequency (f_B) were taken. V_E and V_T for H were significantly higher ($P < 0.05$) than those for R, O, and L throughout the 13.5 min session, while f_B and $ETCO_2$ were not significantly different among the four mixtures ($P > .05$). During tilt, peak V_E and time to peak were not different among mixtures. However, area under the V_E curve was higher for H compared to the other mixtures. These responses indicate an increase in V_E with increased perfusion of the lungs during tilt independent of air mixture inhaled, and are inconsistent with the theory that CO_2 flow to the lungs drives V_E.

48.19

VENTILATORY RESPONSE TO MAXIMAL INCREMENTAL EXERCISE IN HUMANS WITHOUT CHEMOSENSITIVITY. LP Andres, SA Shea, RB Banzett & *DC Shannon Resp. Biol. Prog., Harvard School of Public Health, Boston, MA 02115 and *Mass. Gen. Hosp., Boston, MA 02114

Patients with Congenital Central Hypoventilation Syndrome (CCHS) have absent or low ventilatory response to chemoreceptor stimuli. Surprisingly, these patients have an approximately normal ventilatory response to a single level of mild, steady-state exercise (Shea et al, ARRD 143:A194). We wondered whether CCHS patients, like normals, 1) Increase ventilation in proportion to work load, and 2) Hyperventilate in response to blood lactate accumulation during heavy exercise. We studied 4 children with CCHS and 5 normal children during incremental treadmill exercise to the maximum load tolerated by the subject. We measured V_E, P_{aCO_2} (estimated from P_{ETCO_2}) P_{ETO_2}, V_{O_2}, and V_{CO_2}. During light incremental exercise (V_{O_2} below 25 ml/[kg·min]) V_E was proportional to V_{CO_2} in both groups; the mean change in P_{aCO_2} from rest was less than 1 torr in both groups. All but one subject reached a V_{O_2} of 30 ml/(kg·min). At this higher level of exercise, controls hyperventilated; P_{aCO_2} fell 8 torr from rest, evidence of lactate accumulation. In contrast, CCHS patients did not hyperventilate; their P_{ETCO_2} rose 5 torr from rest to heavy exercise. Thus, chemosensitivity is not necessary for a proportional ventilatory response to graded moderate exercise but is needed to demonstrate the classical ventilatory response during heavy exercise. (HL19170, HL46690, HL07118).

48.20

END-TIDAL CARBON DIOXIDE VARIATIONS DURING EXERCISE IN THE NORMAL MENSTRUAL CYCLE. Bruce Staats, Tracy Williams, and Ken Beck. Mayo Clinic, Rochester MN 55905.

Ventilation is increased both at rest and during exercise in the luteal phase of the menstrual cycle when compared to the follicular phase. Progesterone appears to cause this increase. By the alveolar ventilation equation, increased ventilation would cause a reduction in alveolar (or end-tidal) P_{CO_2} (P_{ETCO_2}). Studies have documented a reduction in P_{ETCO_2} but none have followed P_{ETCO_2} changes sequentially throughout the menstrual cycle. **METHODS:** 9 females, ages 26-33 years were studied once in the follicular phase and 5-7 times 2-3 days apart in the luteal phase. Subjects performed 5-min constant load cycle ergometry at 30, 70 and 90 Watts. P_{ETCO_2} was obtained by averaging the P_{ETCO_2} values during the last 10 seconds of each workload. **RESULTS:** At all exercise levels, P_{ETCO_2} was highest in follicular and early luteal phases; e.g. the P_{ETCO_2} at 30 Watts decreased from 38.6 (follicular) to 36.0 mm Hg 5 days prior menses and tended to rise thereafter. Regardless of day of the cycle, P_{ETCO_2} increased from 30 through 90 Watts (overall mean +2.1 mm Hg). **CONCLUSIONS:** The P_{ETCO_2} during exercise falls and reaches a low-point in the mid-luteal phase, consistent with the increase in the level of progesterone. In spite of this fall, the P_{ETCO_2} increases as exercise level increases. Exercise studies of normal females should be controlled for day of the menstrual cycle. Supported by the American Lung Association of Minnesota.

48.21

SINGLE PATH MODEL SIMULATES PHASE III SLOPE AND DEADSPACE CHANGES OF INCREASED CO_2 PRODUCTION. JE Baumgardner, JD Schwardt, MS Schreiner, PW Scherer and GR Neufeld. University of Pennsylvania, Philadelphia PA 19104.

A single path model (SPM) of lung airways (Weibel A) with a blood source emission term was used to simulate the excretion of CO_2. Cardiac index, $P\bar{v}CO_2$, V_T and breathing frequency (f) obtained from an animal study at 3 levels of CO_2 production induced by 2,4 dinitrophenol were used as input the model to simulate breaths at 3 different V_T and f. VCO_2, normalized phase III slope, airways deadspace and % change from baseline (bl) were calculated. At each V_T both VD_{aw} and phase III slope increased with f and VCO_2 simulating many attributes of the animal study.

V_T/kg ml	f BPM	VCO_2 ml/min (%)	P_{III} L^{-1} (%)	VD_{aw} ml (%)
10.4	15	509 (bl)	1.32 (bl)	230 (bl)
10.1	22	645 (27)	1.73 (31)	252 (10)
11.3	44	1436 (183)	3.03 (130)	328 (43)
14.7	11	487 (bl)	0.91 (bl)	245 (bl)
15.2	15	681 (40)	0.96 (5)	269 (10)
14.4	33	1197 (146)	1.62 (77)	335 (37)
20.2	8	489 (bl)	0.80 (bl)	277 (bl)
20.3	11	684 (40)	0.80 (0)	298 (8)
20.0	24	1092 (123)	0.92 (15)	359 (30)

We conclude that the SPM is an effective tool for integrating lung airway structure with lung function.

48.22

Effect of Increased CO_2 Production and Increased Breathing Frequency on Phase III Slope and Deadspace

MS Schreiner, JD Schwardt, PW Scherer, and GR Neufeld
University of Pennsylvania, Philadelphia, PA 19104

We infused 2,4 dinitrophenol (2,4 DNP) into an anesthetized, mechanically ventilated 35 kg goat to examine the effect of breathing frequency (*f*) and CO_2 production (VCO_2) on phase III slope and airways deadspace (VD_{aw}) independent cardiac index (CI). We adjusted *f* to maintain a physiologic end tidal CO_2 at 3 VT's (10,15,and 20 ml/kg) at baseline (bl) and after each of 2 doses of 2,4 DNP. After the first dose of 2,4 DNP there was a 6% decrease in CI but a 23-44% increase in VCO_2 from bl with increases in phase III slope and VD_{aw} as well (table). After the second dose of 2,4 DNP there was a 21% decrease in CI and a large increase in phase III slope and VD_{aw} (table).

V_T ml/kg	*f*	VCO_2 ml/min (%)	Phase III L^{-1} (%)	VD_{aw} ml (%)
10.4	15	109 (bl)	1.83 (bl)	172 (bl)
10.1	22	134 (23)	3.23 (77)	178 (3)
11.3	44	295 (170)	7.58 (314)	213 (24)
14.7	11	131(bl)	0.24 (bl)	185 (bl)
15.2	15	179 (37)	0.47 (96)	197 (6)
14.4	33	294 (124)	0.88 (266)	216 (17)
20.2	8	132 (bl)	0.14 (bl)	198 (bl)
20.3	11	190 (44)	0.19 (36)	213 (8)
20.0	24	315 (139)	0.35 (150)	238 (20)

We conclude that VD_{aw} and phase III slope are influenced by *f* and VCO_2.

48.23

RECOVERY OF ACINAR INFORMATION FROM CO_2 EXPIROGRAMS. JD Schwardt*, GR Neufeld, JE Baumgardner, and PW Scherer. University of Pennsylvania, Philadelphia, PA 19104.

A previous sensitivity analysis of a numerical single path model (SPM) of respiratory gas exchange with distributed alveolar gas sources showed that decreasing total acinar airway cross sectional area by a factor R results in computed gas expirograms with phase III steepening similar to that observed in chronic obstructive pulmonary disease (COPD) (Schwardt et al, Ann. Biomed. Eng. 19:679-697; 1991). A least squares fitting algorithm was developed to find the optimal R values to match simulated and experimental data. Optimized R values for the SPM were found according to steady state CO_2 washout from 6 healthy subjects and 6 COPD patients. R values were then combined with measured FRC data to calculate average peripheral airspace diameters (d) in each subject, relative to an idealized standard value (d_{STD}). Mean R values for the patients were 63% of those for normals, which relates to the transport limitation observed in disease. Mean airspace diameters for the patients were 235% of those for normals, which may characterize the increase in size and reduction in number of lung airspaces due to tissue erosion in emphysema. The air-phase diffusive conductance in patients was calculated to be 32% of the mean value in normals. These results correlated well with standard pulmonary function tests and represent a first attempt to recover airway structural information from gas washout by integrating numerical computations with experimental data.

48.24

Effect of Tidal Volume and Breathing Frequency on Phase III Slope in Exercising Goats

GR Neufeld, PW Scherer, MS Schreiner
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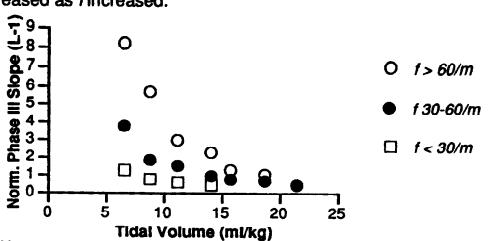
We examined the effect of tidal volume and breathing frequency (*f*) on phase III slope during exercise. We trained 2 tracheostomized goats to exercise on a treadmill and perform a 12 stage exercise protocol. We used a computerized system for breath by breath analysis of V_T, *f*, and normalized phase III slope for CO_2. The data from 15 treadmill runs were pooled and stratified by respiratory rate and tidal volume. Phase III slope increased as V_T decreased. At any given V_T phase III slope increased as *f* increased.



We conclude that phase III slope is heavily influenced by tidal volume and breathing frequency.

48.25

PULMONARY GAS EXCHANGE IMPAIRMENT IN ULTRAMARATHONERS FOLLOWING A 100 MILE RACE AT ALTITUDE. MW Eldridge* JW Severinghaus PE Bickler SC Wood and O Appenzellar. CVRI and Depts of Anesthesia and Pediatrics, UCSF San Francisco CA. 94143 and Lovelace Medical Foundation, Albuquerque NM. 87108

We investigated the effects of prolonged severe exercise at altitude on post-exercise pulmonary gas exchange and P_{50} in 12 ultramarathon runners. The runners competed in the Leadville 100, running 100 miles at a mean altitude greater than 3300M. All studies were performed in Leadville Colo. (3400M), the day prior to and approximately 1 hour after completion of the race. The subjects were studied while resting in a supine position with head elevated 30 degrees. They were fitted with an anesthesia mask to deliver the following gases; ambient air, N_2 plus air ($P_{ET}O_2$=40torr) and O_2 plus air ($P_{ET}O_2$=97torr). Each gas mixture was inhaled for 3 minutes while $P_{ET}O_2$ and $P_{ET}CO_2$ were measured continuously. Arterial saturation (S_pO_2) was measured with a pulse oximeter. Assuming an ideal lung and no shift in the O_2-dissociation curve a calculated saturation (S_cO_2) can be derived from the measured $P_{ET}O_2$ and $P_{ET}CO_2$. Efficiency of gas exchange was then estimated by taking the difference between S_cO_2 and S_pO_2 ($S_{c\text{-}p}O_2$). The pre-race ambient air S_pO_2 was 94.6±1.7 (mean±SD) with a $S_{c\text{-}p}O_2$ of 0.8±0.7. The post-exercise S_pO_2 was 91.0±2.1 with a $S_{c\text{-}p}O_2$ of 4.4±1.5. This saturation gradient widened during hypoxia to 5.9±2.2 and disappeared with supplemental oxygen. Venous blood samples were collected just prior to each ventilatory study. P_{50} was determined by using a standard tonometry method. The samples were divided into equal volumes and equilibrated in N_2 plus 5% CO_2 and 100% O_2. The samples were then mixed together to give a saturation of approximately 50% and the P_{50} determined from the measured PO_2 corrected for pH. P_{50} was 26.5±0.8 and 25.5±1.1 before and after the exercise respectively. This suggests the etiology of the post-exercise desaturation is not related to a shift in the O_2-dissociation relationship. The etiology for the observed limitation in gas exchange is unclear but may be associated with subclinical isolated regions of pulmonary edema.

48.26

DIFFERENCES IN CARDIAC OUTPUT AND DIFFUSION CAPACITY DURING RUNNING IN SPRINT- OR ENDURANCE TRAINED ATHLETES.
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We studied cardiac output and pulmonary diffusion in 6 sprint trained (SP) and 6 endurance trained (END) athletes (national class, 19-26 yr). Maximal oxygen consumption $\dot{V}O_2$, ventilation, capillary pO_2, and lactate were measured in a graded test on the treadmill increased by 2 km/h and 3 min stages up to exhaustion. In a separate test run, the subjects performed three 5 min runs at 70, 85 and 105 % of the 4mmol/l lactic aerobic threshold (LAT). Cardiac output $\dot{Q}$, diffusion capacity TF, FRC, and $\dot{V}O_2$ were measured by multigas rebreathing technique. The test gas contained 0.4% $C^{18}O$, 0.4% C_2H_2, 5% He, 5% SF_6, 35% O_2 and 5% CO_2. Volume of the rebreathing bag was 60% of vital capacity, rebreathing time was 12 s during exercise. Respired gas concentrations were measured by mass spectrometry.

In sprinters, $\dot{Q}$ reached a maximum of 26.1±5.5 l/min at 85% of LAT and decreased at 105% LAT to 23.7±4.5 l/min, whereas in END, $\dot{Q}$ increased linearly up to 26.2±6.1 at 105% LAT. $\dot{V}O_2$ started to level off at 105% LAT in SP, but not in END. In SP, diffusion capacity remained nearly constant at all work loads with maximum TF at 85% LAT (73.1±17.6 ml/min*mmHg). In END, TF increased linearly up to 90.1±30.6 ml/min*mmHg). Capillary pO_2 decreased similarly in SP and END (to 69.3 and 68.2 mmHg), $\dot{V}E$ was significantly higher in SP.

In contrast to endurance athletes, cardiac output and pulmonary diffusion seemed to be limited in sprint trained athletes during running at the lactic aerobic threshold. The validity of these findings is supported by using a $C^{18}O$ and C_2H_2 rebreathing method, not influenced by recirculation.

48.27

THE EFFECTS OF INTENSE EXERCISE ON DLCO AND %SAO2 IN COMPETITIVE ATHLETES. S.P.D. Turner*, D.C. McKenzie, K.C. Coutts, P.G Wilcox*, D.K. Jespersen*, T. K. Cooper*. Division of Sports Medicine, Faculty of Medicine, University of British Columbia, Vancouver, B. C., Canada.

Twelve healthy male endurance trained athletes (age=24.8±3.3 yrs, ht.=181.4±4.8 cm., wt.=75.3±6.7 kg., V̇O2max=67.9±5.6 ml/kg/min) served as subjects in an experiment to examine the relationship between pulmonary diffusion capacity (DLCO) and arterial blood oxygen saturation (%SaO2) following intense exercise. Subjects were divided into two groups based on the minimum %SaO2 recorded (HP47201A ear oximeter) during a V̇O2max test; Non-desaturaters (ND=4) %SaO2>91.0 and Desaturaters (D=8) %SaO2<91.0. Each subject performed 5 minutes of exercise (Mijnhardt electrically-braked cycle ergometer) at a floating workload (360±25 W) to maintain a V̇O2 equal to 90% of the subjects previously determined V̇O2max. DLCO was measured (single-breath carbon monoxide method) one half hour prior to and one hour following the completion of the exercise bout. Both groups showed a significant post-exercise decrease in DLCO (D=40.1 to 37.5, ND=41.7 to 38.7; p<.01). There was a significant 7.5% decrease in %SaO2 in D (97.4 to 90.1,p<.001) and a smaller (4.7%) drop in ND (97.9 to 93.3, p<.05). However, D and ND did not demonstrate a significant correlation between percent decrease in %SaO2 and percent decrease in DLCO (D: r=-.39, ND: r=-.30). Intense exercise results in a decrease in DLCO post-exercise which may indicate the formation of subclinical pulmonary edema. The contribution of these changes to the drop in %SaO2 during exercise is low.

48.28

PRESSURE-DEPENDENT PULMONARY SHUNTING DURING HAPE: THEORY. John W. Severinghaus, Philip E. Bickler and Marlowe W. Eldridge* CVRI and Depts of Anesthesia and Pediatrics, UCSF, San Francisco CA.

Hypothesis: **In HAPE (high altitude pulmonary edema), exercise or hypoxia, by increasing PAP (pulmonary artery pressure), may reperfuse edematous vascular beds closed by HPV (hypoxic pulmonary vasoconstriction) causing PDS (pressure-dependent shunt).** HPV resistance is very pressure-dependent (Benumof, JAP 38:846, 1975). HAPE is effectively prevented or promptly treated (e.g. S_aO_2 rises) with some pulmonary vasodilators, e.g. nifedipine (Bärtsch, NEJM 325:1284, 1991; Oelz, Clin Res 39: 178A, 1991), furosemide and α blocker phentolamine (Hackett, FASEB J 6: 3082, 1992). Improvement occurs before significant clearing of HAPE, as if HPV homeostasis were made more effective by falling PAP. With near maximum work at altitude PAP rises more than at sea level, and S_aO_2 falls 9-15% in normals (Groves, JAP 63: 521, 1987).

This PDS hypothesis arose from 3 incidental observations at 3810M altitude in subjects with mild pulmonary dysfunction (presumed subclinical HAPE): 1) At rest, S_aO_2 was only slightly subnormal (≃80-88%) but, with 5 min mild cycle exercise ($\dot{V}O_2$≃1.5 l·min^{-1}), fell 10-20%, while in fit subjects S_aO_2 hardly fell. 2) Elevation of $P_{ET}O_2$ during exercise from ambient, ≃60, to 90-100 mmHg unexpectedly increased S_aO_2 to >95% in 3 subjects with objective pulmonary dysfunction. 3) Reducing F_IO_2 at rest caused more desaturation in less fit subjects. The role of lower cardiac output and S_vO_2 with constant but abnormal V̇/Q̇ could not be excluded. We plan to measure the effects of exercise and varying $P_{ET}O_2$ on PAP, CO, S_vO_2 and shunt in HAPE susceptible subjects during acclimatization at 3810M altitude. Clinical improvement seen with reduction of PAP may result not only from slowing edema formation, but from more complete blood diversion by HPV from poorly ventilated regions.

48.29

PULMONARY ARTERY PRESSURE AT HIGH ALTITUDE: INFLUENCE OF ß-BLOCKADE DETERMINED BY DOPPLER ECHOCARDIOGRAPHY
Mark A. Selland,* Eugene E. Wolfel, John T. Reeves. Univ of Colorado Health Sciences Center, Denver, CO 80262

The purpose of this investigation was to determine the effect of chronic ß-blockade on mean pulmonary artery pressure (MPAP) during exposure to 4300 m (USARIEM, Pikes Peak, CO). Eleven male sea level residents were divided into control and drug groups, which received either placebo (C) or propranolol 240 mg/day (D). Doppler and 2D echocardiography were performed on resting supine subjects at sea level, and after 1 and 3 weeks at high *altitude*. MPAP was calculated from the ratio of acceleration time (ACT) to ejection time (RVET), MPAP = (0.55-ACT/RVET)/0.0055, using the doppler flow signal obtained from the right ventricular outflow tract. Cardiac output (CO) was derived from the product of the flow velocity integral of the left ventricular outflow tract, aortic cross-sectional area and heart rate.

	Sea Level		High Altitude	
	MPAP(mmHg)	CO(l/min)	MPAP(mmHg)	CO(l/min)
C (n=4)	21±4	4.4±0.6	30±6	5.3±0.4
D (n=6)	21±3	4.5±0.2	34±3*	4.3±0.4

*p<0.05, compared to sea level

MPAP related to arterial oxygen saturation (p<0.001, r=0.604), but did not show a relation to heart rate or total blood volume. In summary, the 2 groups had similar pulmonary pressor responses to high altitude, but ß-blockade resulted in a lower cardiac output and a greater increase in total pulmonary vascular resistance (p<0.01, compared to sea level and high altitude C).

48.30

FUROSEMIDE ATTENUATES THE EXERCISE-INDUCED RISE IN PULMONARY ARTERY WEDGE PRESSURE IN HORSES. Murli Manohar, Dept. Vet. Biosci., Univ. Illinois, Urbana, IL 61801.

Using catheter-mounted micro-tip-manometers (whose *in-vivo* signals were matched with conventional fluid-filled catheter transducers leveled at the scapulohumeral joint), we studied right atrial (RA), right ventricular (RV), pulmonary artery (PA) and pulmonary artery wedge (PAW) pressures in 8 healthy horses at rest and during galloping on a treadmill at 13 m/s for 2 min. Thirty min after completing control exercise (EX) measurements, furosemide was administered IV @ 1 mg/kg. Prefurosemide and postfurosemide heart rate values for rest (37 ± 2 beats/min) as well as EX (213 ± 5 beats/min) were similar. Prefurosemide, mean RA, PA and PAW pressures increased significantly from resting values of 8 ± 2, 31 ± 2, and 18 ± 2 mmHg, respectively to 44 ± 4, 89 ± 5, and 56 ± 4 mmHg with EX at 13 m/s. Furosemide administration resulted in marked diuresis and resting values of mean RA, PA and PAW pressures decreased significantly to 1 ± 1, 27 ± 2 and 11 ± 2 mmHg, respectively, 4 hours postfurosemide. Although these pressures increased markedly with EX (corresponding values being 31 ± 5, 79 ± 6 and 44 ± 4 mmHg), these postfurosemide EX values were significantly (P<0.05) less than those recorded with prefurosemide EX. Considering that intravascular pulmonary capillary pressure may be halfway between mean PA and PAW pressures, its value during prefurosemide EX (73 ± 5 mmHg) exceeded (P < 0.05) that during EX carried out 4 hours postfurosemide (61 ± 5 mmHg). Attenuation by furosemide of the EX-induced rise in pulmonary capillary pressure may play a role in limiting/reducing the extent of exercise-induced pulmonary hemorrhage (EIPH) in horses.

48.31

CARDIOPULMONARY MECHANISMS OF EXERCISE-INDUCED PULMONARY HEMORRHAGE IN THE EQUINE ATHLETE. H.H. Erickson, S.C. Olsen*, B.S. Lowe*, N. Pelletier*, and C.P. Coyne*. Kansas State Univ., Manhattan, KS 66506.

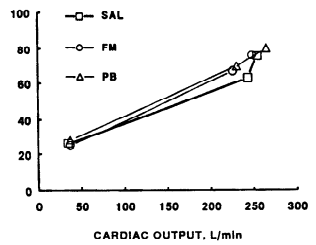
Exercise-induced pulmonary hemorrhage (EIPH) commonly occurs in the equine athlete; however, it is rarely observed in other animals. Furosemide, a diuretic, is used in the horse racing industry to prevent or attenuate EIPH. We have conducted studies on 6 Quarter Horses and Thoroughbreds to determine the causes and mechanisms of EIPH and the rationale for using furosemide. Right atrial (RAP), pulmonary arterial (PAP), and carotid arterial (CAP) pressures were measured during exercise on a high-speed treadmill to determine the magnitude of pressure changes and other hemodynamic variables during exercise. The effects of various dosages of furosemide administered 4 h before exercise were studied. During exercise, increases in treadmill speed were associated with increases in RAP, PAP, CAP, and heart rate. Furosemide (0.25 to 2 mg/kg) administered 4 h before exercise, reduced RAP and PAP during exercise in a dose-dependent manner, but did not influence heart rate. Mean CAP was reduced by the 2-mg/kg furosemide dosage during exercise at 9 and 11 m/s, but not at 13 m/s. Furosemide may mediate some of its cardiopulmonary effects by vasodilatory activities that directly lower PAP, but also increase venous capacitance, thereby reducing venous return to the atria and cardiac filling. (Supported by the American Quarter Horse Association and the Kansas Racing Commission).

48.32

ACUTE CYCLOOXYGENASE BLOCKADE (CYB) DOES NOT ALTER PULMONARY ARTERY PRESSURE-FLOW ($\dot{Q}$) CURVES IN HORSES. N. Pelletier*, S.C. Olsen*, C.P. Coyne*, B.S. Lowe*, D.E. Leith, and H.H. Erickson. Depts. Clin. Sci. and Anat. & Physiol., Kansas State University, Manhattan, KS 66506, U.S.A.

Mean Ppa is higher in horses than in humans, both at rest (~30 vs ~15 mmHg) and during exercise ($\geq$ 80 vs $\leq$ 37 mmHg). The mechanisms are unknown. To see if metabolites from the CY pathway contributed to the high Ppa in exercising horses, we compared Ppa-$\dot{Q}$ curves after the I.V. administration of saline (SAL) and the CY inhibitors flunixin meglumine (FM) and phenylbutazone (PB), in 1 Quarter Horse and 4 Thoroughbreds at rest and after 2 min galloping at 9 and 13 m/s on a level treadmill. We calculated O_2 consumption ($\dot{V}O_2$) from measurements of respired gas composition and flow, and $\dot{Q}$ from $\dot{V}O_2$ and measurements of arterial and mixed-venous O_2 content (Fick).

CYB did not change the slope and intercept of Ppa-$\dot{Q}$ curves. If smooth muscle contraction was present and influenced Ppa-$\dot{Q}$ curves, it was insensitive to CYB. Thus CY metabolites do not appear to contribute to the high Ppa of exercising horses.



Funded in part by the American Quarter Horse Association and the Medical Research Council of Canada.

48.33

β BLOCKADE OF HORSE BRONCHIAL ARTERY BLOOD FLOW DURING EXERCISE. R. D. Gleed, A. Dobson and R.P. Hackett*. College of Veterinary Medicine, Cornell University, Ithaca, NY 14853.

We wished to establish whether β-adrenergic vasodilatation of the bronchial bed occurred during exertion. Blood flow was measured with an implanted acoustic transit time probe (Transonics Systems Inc.) during two 2.4 Km, sub maximal periods of treadmill exercise separated by a short rest. Without blockade flow decreased as exercise began, but thereafter steadily increased. Flow peaked when the horse was slowing or had stopped after exercise. Systemic arterial pressure rose more quickly than flow during exercise and was still high when flow was maximum, but by then, pulmonary pressure had declined. The steady rise in flow during exercise was inhibited by propanalol, but the after-dilatation after exercise was invariably observed. Blockade was confirmed by the lack of effect of injection of isoprel, normally a potent dilator of the bronchial bed, and by the absence of sweating during exertion. We conclude that maximum pressure is transmitted from the artery to the bronchial capillary bed during the after-dilatation following exercise. Unlike the steady flow rise during exercise, this dilatation was insensitive to propanalol. These patterns were similar in normal horses and those with a confirmed history of bleeding into the airways.

(Supported by the Zweig Memorial Fund. and N.Y.H.B.P.A.)

48.34

SHEEP AS AN EXPERIMENTAL EXERCISE MODEL. Kenneth T. Dodd*, Adolph J. Januszkiewicz, Carol A. Bossone, and Thomas G. Mundie. Walter Reed Army Institute of Research, Division of Medicine, Department of Respiratory Research, Washington D.C. 20307-5100.

One method for assessing the body's capacity to do work is through exercise testing. Maximal exercise challenges yield valuable insight into integrated cardiopulmonary function and are widely used to assess cardiac and pulmonary disease states in humans. There is general agreement that oxygen consumption ($\dot{V}o_2$) is the best available measurement of total muscular effort expended during exercise. Moreover, maximum $\dot{V}o_2$ ($\dot{V}o_2max$) is accepted as an index of maximal aerobic capacity and most often used as the standard for cardiorespiratory fitness. The literature contains extensive information on $\dot{V}o_2max$ in humans, wild and domesticated animals, and a variety of laboratory species. Unfortunately, the information available on the adaptive changes in sheep during maximal exercise is limited, despite an extensive basic cardiopulmonary database for this specie.

Three maximal exercise challenge protocols were developed and evaluated for sheep. Each challenge used varying combinations of speed and grade to ascertain the most effective protocol for determining Vo_2max in sheep. Data collected during challenges included $\dot{V}o_2$, $\dot{V}co_2$, time on treadmill, heart rate, cardiac output, blood gases and a variety of chemical parameters. The effect of alpha-blockers, beta-blockers, and splenectomy were evaluated using the model. The model was also used to evaluate maximal exercise capacity after a several systemic insults: four levels of pulmonary contusion injury, toxic gas inhalation (NO_2), and methemoglobinemia. The changes in exercise tolerance for each insult is reported. This effort has shown the sheep to be a suitable large exercise animal model, providing insight into integrated heart/lung function and decrement in performance.

48.35

THE EFFECT OF HYPOXIC EXERCISE ON RAT LUNGS. RB Schoene, S Goldberg, D Luchtel, R Albert, and T Martin. Univ. of Washington, Seattle WA 98195.

Exercise at high altitude in some humans causes pulmonary edema which is characterized by a high protein content. The mechanism of the leak is not clear. We studied four groups of rats (♂,n=6): normoxic rest (NR), normoxic exercise (NE), hypoxic rats at rest (HR) and after 2 hrs. of exercise (HE) during 18-20 hours of normobaric hypoxia (FIO2=0.1). At time of sacrifice we studied blood for von Willebrand's *antigen (vWA)* and lungs with bronchoalveolar lavage (BAL) for cells and protein and with light (LM) and electron microscopy (EM) for morphology. BAL was similar in all groups, but both HR and HE had significantly elevated levels of vWA, indicative of endothelial damage. LM was similar in all groups, but EM showed mild interstitial edema in HR and damage of epithelial type 1 and endothelial cells (blistering and stripping from basement membrane) in HE. Results suggest that hypoxia causes early disruption of both epithelial and endothelial cells which may give insight into evolution of pulmonary edema.

48.36

THE LUNGS DO NOT RESPOND BY STRUCTURAL ADAPTATION TO INCREASED O_2-DEMAND IN GUINEA PIGS. V.P. Stalder-Navarro*, D.L. Turner*, H. Hoppeler* and E.R. Weibel. Dept. of Anatomy, University of Berne, CH-3000 Berne 9, Switzerland

An increase in O_2-demand was induced in growing guinea pigs through endurance exercise training by running on a treadmill for 6 weeks (a high intensity intermittent stimulus) or through shortterm (6 weeks) or longterm (70 weeks) cold-exposure (a low intensity continuous stimulus). Both stimuli led to a similar significant increase by 1.2-fold in maximal O_2-consumption, VO_2max/Mb, but had different effects on the average daily O_2 consumption (VO_2dav); the VO_2dav was significantly reduced (-14%) in the trained guinea pigs and increased in the cold-exposed group (by 1.5-fold in the shortterm and by 2-fold in the longterm cold-exposed guinea pigs). The morphometric analysis of the pulmonary gas exchanger showed that training had not affected the lung volume nor the internal structure of the lung. Cold-exposure, however, resulted in a higher mass-specific lung volume (V_L/Mb) in both cold-exposed groups, which could be the result of either an accelerated lung growth or a retardation in body growth due to cold-exposure. The chief morphometric parameters of pulmonary diffusing capacity D_LO_2 (alveolar and capillary surfaces, capillary volume, barrier thickness) showed no differences between the groups. We, therefore, conclude, that the 1.2-fold increase in VO_2max resulting from exercise training proved insufficient to cause structural adaptation. Neither did the continuous but low intensity stimulus of cold environment cause the structures that support gas exchange to increase in size, at least in guinea pigs. The lung appears rather resilient to induced variation in functional capacity, possibly as a result of the observed redundancy in morphometric diffusing capacity.

49.1

Relationship between oxygenation of skeletal muscle and blood lactate concentration during progressive maximal bicycle exercise. Sachiko Homma, Nobuharu Fujii*, Hideo Eda*, and Haruo Ikegami Inst. of Health and Sport Sciences, Univ. of Tsukuba, Ibaraki, 305, Japan

Using near-infrared spectroscopy (wave lengths of 780nm, 805nm and 830nm), we monitored changes in the oxy-, deoxy- and total hemoglobin contents of the vastus lateralis muscle at rest, during progressive maximal bicycle exercise, and during inflation of a thigh cuff to 250mmHg in 8 healthy male volunteers who gave informed consent. Gas exchange parameters were measured continuously, and electrocardiogram and impedance-cardiogram were also obtained continuously. Arterialized blood samples were obtained from a hand vein at every exercise intensity level. During low intensity exercise, low levels of deoxyhemoglobin and total hemoglobin were observed. These changes probably reflected increase in venous return. Abrupt decrease in oxyhemoglobin content and increase in deoxyhemoglobin content were observed at 150-watt exercise intensity. These findings probably reflected increased O2 extraction by the exercising muscle. At the peak of exercise intensity, the mean content of oxyhemoglobin expressed by relative range from rest to cuff inflation was 55.0± 15.7%. Blood lactate concentration was increased compared to the resting value at 120-watt exercise intensity. These results suggest that relatively high level of O2 is present in the vastus lateralis during exercise which is strenous enough to increase blood lactate concentration.

49.2

ERYTHROPOIETIC RESPONSE TO INTERMITTENT ALTITUDE EXPOSURE. G.W. Leadbetter, R.A. Robergs, D. A. Clark, B.C. Ruby, D.J. Lium, S. B. McMinn, T.W. Chick. Univ. of New Mexico, Albuquerque, NM. 87131

To evaluate the erythropoietic response to altitude, six subjects (3 males, 3 females) were exposed to intermittent high altitude (2.5 hrs/day @18,000ft/5,538m) for six consecutive days. Venous blood samples were obtained prior to exposure (baseline), pre and post exposure (days 1, 3 and 5) and on alternate days for two weeks after exposure. Blood was assayed for erythropoietin (EPO), bilirubin (BIL), hemoglobin (Hb), and prepared for hematocrit (Hct) and reticulocyte (RTC) counts. The EPO level for pre-post exposures were 16.2±0.8 to 17.3±1.2, 14.8±1.0 to 15.3±1.0 and 14.8±1.2 to 18.1±1.1 for days 1, 3, and 5, respectively. Baseline and four day post exposure EPO values were 16.2±0.8 and 15.9±0.8, respectively. Although EPO increased after each exposure, all values remained within the normal range (4-36mU/ml). Hemoglobin and Hct levels remained constant, whereas RTC increased significantly from baseline (1.0±0.1%) by day 4 and day 5 (1.4±0.1 and 2.5±0.3%, respectively). Thereafter, RTC counts decreased gradually to 1.5±0.1%, during the two week post exposure period. During exposure, (day 2-5) indirect BIL exhibited peak levels which exceeded direct BIL levels. Total BIL showed a pulsatile pattern throughout the 3 weeks of data collection. The data indicate that intermittent altitude exposure provides minimal erythropoietic stimulation, yet significantly increased RTC. It remains unclear if erythropoiesis is accompanied by increased RBC destruction or whether the elevated RTC counts increase erythrocyte counts.

49.3

PHYSIOLOGICAL RESPONSES AND ENERGY COSTS OF ROCK CLIMBING AT VARIOUS DIFFICULTY LEVELS. P. Watts, K. Drobish*, S. Ringheim*. Northern Michigan University, Exercise Physiology Laboratory, Marquette, MI 49855.

Although rock climbing has evidenced rapid growth as a recreational activity and international competitive sport, no known studies have directly assessed the oxygen uptake and energy requirement of the activity. This study employed an 8x12 ft rock climbing "tread wall" (TW) fitted with competition-type modular holds to present a recycling 24-ft climbing surface. Sixteen experienced rock climbers completed 4-min continuous climbing bouts on the TW at 80, 86, 91, 96 and 102 degree angles with 6 mins rest between bouts. Distance climbed (D) was measured to the nearest foot by a mechanical counter. Heart rate (HR), recorded via telemetry, was averaged each 5 secs. Expired air was collected continuously via an automated open circuit system and analyzed each 20 secs. Energy expenditure (EE) was estimated from measurement of oxygen uptake (VO2) and respiratory exchange ratio (R) and expressed as kcal/min and kcal/10-feet climbed. The average of right and left handgrip force (HG) and arterialized blood lactate (BL) were determined immediately following each climbing bout. Results are presented below:

Angle (deg)	D (ft)	HR (bpm)	VO2 (ml/kg/min)	EE (kcal/min)	Kcal /10ft	BL (mmol/l)	HG (kg)
80	89.9	156	31.3	11.0	1.26	3.6	43.6
86	81.1*	165*	31.7	11.2	1.42	4.0	40.3
91	66.4*	171*	31.2	11.0	1.98	4.9*	35.4*
96	43.8*	173*	29.5	10.4	3.03*	5.1*	31.0*
102	27.0*	171	30.9	10.9	4.76*	5.9*	34.2

*Indicates p>0.05 vs preceeding angle.

While HR increased with steepness, VO2 remained constant, thus EE did not vary with climbing angle. When expressed relative to distance climbed however, EE was significantly higher at the steeper angles. HG decreased with steepness and was negatively correlated with BL (r=-0.96). The mean VO2 values for all angles varied between 55.5 and 63.4 % of each subject's maximum VO2 as determined via treadmill running.

Supported in part by Brewer's Ledge, Inc.

49.4

DYNAMICS OF LACTATE AND OXYGEN UPTAKE DURING EXERCISE. Marco E. Cabrera and Howard J. Chizeck*. Case Western Reserve University, Cleveland, OH 44106

Determination of the dynamics of oxygen uptake ($\dot{V}O_2$) and blood lactate concentration (LA) as it relates to exercise intensity is essential to the understanding of exercise energetics. To determine this dynamics, two responses (LA,$\dot{V}O_2$) to an incremental work rate (WR) input were analyzed using system identification techniques. A time series model of the LA-$\dot{V}O_2$ kinetics system, with WR as its input and both $\dot{V}O_2$ and LA as its outputs was fitted to published data from experimental trials with ten different subjects (JAP 59:935, 1985). To detect potential changes in the system dynamics, a weighted recursive least-squares identification algorithm was used. The system parameters were identified as a function of time for each data set. Two major transitions, dividing the time domain into three regions, were apparent from the time courses of the estimated parameters. The average time difference between the two transitions was 4.8 min. The first transition occurred at a mean $\dot{V}O_2$ of 53±8 % $\dot{V}O_2$max and a mean LA of 1.1±0.1 mEq/L. The second transition occurred at a mean $\dot{V}O_2$ of 77±9 % $\dot{V}O_2$max and a mean LA of 2.9±0.9 mEq/L. These results expose the time varying nature of the LA-$\dot{V}O_2$ kinetics system during exercise. It appears that there are three main domains of exercise intensity or metabolic rate, between unloaded pedalling and peak exercise ($\dot{V}O_2$max). Each of these domains is associated with different parameter values and consequently distinctive dynamics.

49.5

OXYGEN UPTAKE KINETICS FOLLOWING ENDURANCE TRAINING. Stephen R. Norris and Stewart R. Petersen*. University of Alberta, Edmonton, Alberta, Canada, T6G 2E1

This study examined transient oxygen uptake responses before and after eight weeks of specific endurance training of six competitive male cyclists. Each cyclist undertook three equal ascending transitions in power output from unloaded cycling to approximately 78, 156, and 235 watts (T1, T2, T3) pre and post training. Steady state criteria (ventilation, oxygen uptake, and heart rate) were established to signify each transient phase. The endurance training involved five sessions per week (four sessions at a heart rate intensity equal to anaerobic threshold, and one session of low intensity cycling), of 40 minutes rising by five minutes every second week. This training was performed on cycle rollers with the cyclists using their own equipment. Gas exchange information was collected using a SensorMedics 2900z metabolic measurement system operating in breath-by-breath mode. The raw data were then time averaged (every 10 seconds) and described via a single exponential equation incorporating a time delay feature. The time constant (t) and mean response time (MRT) for each transition were then analysed for statistical significance (ANOVA/post hoc Scheffé F-test where appropriate). The results revealed a gradual slowing of oxygen kinetics with increasing workload, although these were only significant for T1 vs T3 and T2 vs T3 ($p<0.05$), as well as significantly faster t and MRT values post-training ($p<0.05$) for all three transitions. It would seem that, with appropriate methodological care, gas exchange kinetics may provide information concerning adaptation to training in addition to normal exercise testing procedures.

Supported by Sport Canada.

49.6

GAS EXCHANGE KINETICS IN ELDERLY. C. Marconi, M. Marzorati, B. Grassi, M. Conti, M. Bordini, and P. Cerretelli. I.T.B.A.- Sect. of Physiology, C.N.R, Milano, Italia.

The kinetics of the $\dot{V}O_2$ readjustment at the mouth at the onset of a constant-load aerobic exercise (t1/2 $\dot{V}O_2$ on-, s) reflects the time course of the slowest among the processes controlling O_2 flow to, and O_2 utilization by, the muscles. To evaluate the combined effects of training and aging, the t1/2 $\dot{V}O_2$ on- at the onset of a 5 min constant-load cycle ergometer exercise corresponding to ~50% of the individual $\dot{V}O_2$max was assessed in 66 male master athletes (MA) aged 37-78 yr, by means of a metabolic cart (SensorMedics MMC4400tc). Comparison was made with homologous data obtained on 12 healthy sedentary young subjects (YS 24-37 yr) and on two groups of healthy untrained middle-aged and elderly subjects (13 males, aged 49-71 yr, MUT, and 20 females, aged 53-81 yr, FUT) performing ~50% of their $\dot{V}O_2$max. MUT and FUT were also tested after a two months period of aerobic training (30 min cycling sessions at about the anaerobic threshold three- fold a week). RESULTS: 1) The t1/2 $\dot{V}O_2$ on- of MA, up to 65 yr, was as fast as that of YS (31 vs 29s), whereas >65 yr the kinetics was delayed (44s). 2) The mean t1/2 $\dot{V}O_2$ on- of MUT and FUT was ~45s independent of age and sex. 3) After training, the t1/2 $\dot{V}O_2$ on- of both MUT and FUT approached the values for MA (~30s). CONCLUSIONS: 1) In MA up to 65 yr no age-related decrease of the rate of readjustment of $\dot{V}O_2$ at the onset of a submaximal constant-load exercise is found. 2) MUT and FUT are characterized by a delayed kinetics compared to MA. 3) Moderate aerobic training improves considerably the rate of gas exchange at the onset of exercise in MUT and FUT at all the investigated ages.

49.7

ECONOMY DURING ENDURANCE EXERCISE FOLLOWING MAGNESIUM SUPPLEMENTATION L.R. Brilla Exercise and Sport Science Laboratory, Western Washington University, Bellingham, WA 98225

The purpose of this study was to determine the possible effect on economy of endurance exercise following magnesium supplementation. In this study, fourteen trained subjects were given magnesium oxide at 8 mg per kg body weight per day, including the amount assessed from a 3-day diet record, or a placebo, in a double blind fashion. All subjects completed a baseline graded exercise test on a treadmill and completed a 90%max endurance run to volitional fatigue. After 4 weeks of supplementation, the subjects completed a 90%max endurance run, then crossed over to the other condition for 4 weeks before completing their final 90%max endurance run. Respiratory gases, heart rate, and ratings of perceived exertion using the Borg scale, were collected at each session. Significant differences ($p<.05$) were noted for oxygen consumption adjusted for body weight: 47.3 ± 4.6 mbg.kg^{-1}.min^{-1} for the placebo group and 45.2 ± 4.9 mg.kg^{-1}.min^{-1} for those on magnesium supplementation; and minute ventilation was significantly different: 100.1 ± 22.8 L.min^{-1} versus 94.8 L.min^{-1}, for placebo versus magnesium group, respectively. There appears to be slightly more physiological stress due to the slightly higher, yet statistically different, oxygen consumption and ventilation in the placebo trial as compared to the magnesium supplementation condition. This indicated an enhanced aerobic economy during magnesium supplementation that requires further study. There were no significant differences in ratings of perceived exertion using the Borg scale at any of the collection intervals during the 90%max run to exhaustion indicating that magnesium did not ameliorate the perception of effort in trained subjects when using this measurement scale.

49.8

ROLE OF PULMONARY O_2 DIFFUSION FOR ARTERIAL O_2 SATURATION AND VO_2MAX. P.K.Pedersen, C. Andersen*, K. Madsen* and K.Jensen*. Dept. Physical Education, Odense University, Denmark.

The role of pulmonary O_2 diffusion for the maintenance of arterial O_2 saturation (%SaO_2) in exercise and its significance for VO_2max was examined. Young, healthy volunteers of varying fitness level (5 trained females (TF), 5 trained males (TM) and 7 male elite road racing bicyclists (EB)) performed incremental cycle ergometer tests to exhaustion while inspiring normoxic air (NOX) or a 30% O_2 mixture (HOX). The decrease in radial artery %SaO_2 from rest to exhaustion in NOX (98.5% to 95.3%; $p< 0.001$) disappeared in HOX where %SaO_2 remained 99-100%. Acid-base status was similar in NOX and HOX. VO_2max in NOX averaged 52, 62 and 73 ml/min/kg in TF, TM and EB, respectively, and increased by an average of 5% in HOX ($p<0.001$) with no significant differences between groups. The individual data, however, showed a significant correlation between the degree of desaturation in NOX and the HOX-induced increase in VO_2max. This supports that pulmonary O_2 diffusion contributes to the limitation of VO_2max in trained individuals as seen earlier in non-invasive studies (Powers et al. JAP, 66: 2491-2495, 1989).

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49.9

CONTRIBUTION OF CENTRAL AND PERIPHERAL FACTORS TO THE VARIATION IN MAXIMAL OXYGEN CONSUMPTION IN PHYSICALLY ACTIVE HUMAN SUBJECTS. D. Prud'homme, P. Boulay, M.R. Boulay, P. Barbeau and J.A. Simoneau. Physical Activity Sciences Laboratory, Laval University, Ste-Foy, Canada.

The purpose of this study was to determine the relative contribution of the oxygen transport system and peripheral factors to maximal oxygen uptake (VO_2 max) in physically active (n=15) subjects (21.6 ± 4.0 yrs of age; 73.5 ± 8.0 kg of body weight). VO_2max was determined during a maximal ergocycle test and maximal cardiac output was measured by a CO_2 rebreathing technique. Values of VO_2max and of maximal cardiac output reached 59.2 ± 6.5 mlO_2/kg/min and 445 ± 73 ml/kg/min, respectively. Citrate synthase (CS) activity was also measured in muscle samples taken from the vastus lateralis and reached 16.0 ± 3.4 U/g wet weight. No significant association was observed between values of maximal cardiac output and muscle CS activity. However, maximal cardiac output ($r=0.74$; $p<0.05$) and CS activity ($r=0.52$; $p<0.05$) showed significant correlations with VO_2max/kg. Multiple regression analyses (F ratio=13.7) revealed that the relative contribution of maximal cardiac output and level of CS activity to the variation in VO_2max reached about 60% and 30%, respectively. These results suggest that both central and peripheral factors contribute to the variation in maximal oxygen uptake in physically active subjects.

49.10

PHYSIOLOGICAL PROFILES AND TRAINING OF DANISH ELITE KAYAKERS. K. Jensen* and B. Larsson* (SPON: N.H. Secher) Team Denmark testcenter, Dept. of Physical Education, Odense University, and Exercise Physiologic Unit, Rigshospitalet, DK-2100

Work rate (W), heart rate (HR), oxygen uptake (Vo2), and blood lactate (BL) were determined, and oxygen deficit (OD) was estimated during paddling on a kayak ergometer in seven male kayakers (age 21 (range 19-27) years, height 1.88 (1.87-1.91) m, weight 78 (68-82) kg, and body fat 11 (7-15) %). HR and BL were also determined during paddling in a kayak. Measurements were made in the early part of the rowing season, and before the World Championship (WC). Training volume and intensity were registrated six wks prior to each test. During simulated 500 and 1000 m races - 1.5 and 3.5 min - on the ergometer before WC, W was 314 (269-335) and 271 (230-289) watt, HRmax 188 (181-199) and 191 (184-202) beats/min, Vo2max 4.36 (4.00-5.51) and 4.78 (4.26-5.64) l/min, BLmax after exercise 11.3 (10.6-14.2) and 11.3 (8.2-16.3) mmol/l, and OD 46 (32-63) and 58 (39-75) ml/kg, respectively. During submaximal paddeling on the ergometer, W and HR at onset of BL accumulation (4 mmol-OBLA), was 192 (172-212) watt and 177 (163-181) beats/min corresponding to 81 (76-87) % of Vo2max (3.5 min). Mechanical efficiency was 14 (13-15) %. Training volumen was 12 (8-16) hours/-week and did not change during the season. In the early and late season 60 (50-90)% and 12 (0-15)% of the training volumen was spend on weight lifting, respectively, and the rest between ergometer training and kayaking. No difference was found in HR(OBLA) between the boat and the ergometer. Physiological profile in the early and the late season did not change, exept for body weight which decreased ($P<0.05$). In conclusion, in spite of individual changes, training during the summer did not change physiological profile in this group of well trained paddlers.

49.11

EFFECTS OF BODY MASS (M_b) ON MITOCHONDRIAL AND CAPILLARY VOLUME DENSITIES, AND MITOCHONDRIAL INNER SURFACE AREA Sv(im,mi) IN FLIGHT MUSCLE, HEART AND LIVER OF HUMMINGBIRDS.

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The slope of the allometric regression of specific oxygen consumption (VO_2/M_b) during hovering flight in the 7 hummingbird species of the matched set is -0.6. Morphometric analysis of flight muscles - pectoralis (PC) and supracoracoideus (SC) -, heart (H) and liver (L) of 2 species of hummingbird with different M_b reveal the following results (in %) for mitochondrial volume density:

	V(mi,mf)			
Animal/Tissue	PC	SC	H	L
Amazilia lactea (5g)	34.21	32.54	32.70	18.12
Eupetomena macroura(10g)	28.81*	26.13*	32.58	19.01

* significantly different (ANOVA)

Capillary volume density was not different among the 2 species, being around 8% in PC, SC and H, and 17% in L. Sv(im,mi) was also similar in the 2 species considered, but the values were twice as high than those observed previously in mammals (approx. 60 x 30 m^2 cm^{-3} mitochondria). The results indicate that smaller species of hummingbirds are capable of attaining higher VO_2/M_b, mainly because they have a higher V(mi,mf) in their flight muscles.

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49.12

$\dot{V}O_2$ AND CARDIAC OUTPUT DURING REST EXERCISE AND EXERCISE-EXERCISE TRANSIENTS Dieter Leyk, Uwe Hoffmann*, Dieter Eßfeld, Klaus Baum, Hans-G. Wunderlich, Jürgen Stegemann. Physiologisches Institut der Deutschen Sporthochschule Köln, Carl-Diem-Weg 6, W-5000 Köln 41, Germany

The dynamics of external gas exchange during exercise is influenced by pulmonary, cardiovascular and metabolic factors. During rest-exercise transitions the interaction of these factors is more complex than during exercise-exercise transients. In the present study we directly compared, in upright and supine body position oxygen uptake ($\dot{V}O_2$) and cardiac output (CO) responses to step changes in exercise intensity.

Nine students performed three bicycle ergometer tests in upright and supine body position: rest-20W, 20W-80W, 20W-140W. $\dot{V}O_2$ was measured breath-by-breath while CO was determined beat-by-beat by means of a Doppler device. The probe was positioned in the suprasternal notch and directed towards the aortic root.

Upright position: When starting from the 20W baseline the $\dot{V}O_2$ responses showed a first, mainly cardiovascular component over the first 30s, followed by a second, metabolic component at constant CO.

The rest-exercise transition were characterized by a faster early CO kinetics leading to steady-state values in about 10s. The $\dot{V}O_2$ kinetics showed a parallel acceleration of the first component.

Supine position: The $\dot{V}O_2$ kinetics generally showed no fast CO- and $\dot{V}O_2$ components of comparable magnitude. On all WL level CO was found higher than in upright position.

This study was supported by DARA GmbH/BMFT (QV 8735)

50.1

POST-EXERCISE CARDIAC AUTONOMIC REGULATION RELATED TO EXERCISE INTENSITY. N. Hayashi*, Y. Nakamura, and I. Muraoka Waseda Univ., Tokorozawa, Saitama, 359 JAPAN

Eight healthy subjects, after signing an informed consent, performed two kinds of constant load exercises at the work rate corresponding to 20% and 100% of the individual ventilatory threshold (T_{VENT}) in addition to the exhaustive incremental exercise using a cycle ergometer. Blood pressure (BP) and oxygen uptake (V_{O_2}) as well as the beat-by-beat recording of R-R intervals were measured until 10 min after the exercises. Spectral analysis was applied to heart rate variability (HRV) data sets of 5 min before, last 5 min during, and 8 to 10 min after the exercises. The low frequency (0-0.15 Hz; LO) and the high frequency (0.15-0.5 Hz; HI) areas under power spectra were calculated for evaluating sympathetic (LO/HI) and vagal (HI) activities. The recovery for 10 min was sufficient to settle both V_{O_2} and BP even after the exhaustion. Comparing to the pre-exercise value, however, HI was still suppressed until 10 min after the 100%T_{VENT} exercise (522 ± 300 vs. 122 ± 63 msec^2, $p < 0.05$) while it was recovered at 10 min after the 20%T_{VENT} one (353 ± 122 vs. 487 ± 159msec^2). These results suggest that the recovery of the cardiac autonomic regulation especially after a moderate to high intensity exercise was later than those of the blood pressure as well as the oxygen uptake.

50.2

SYMPATHETIC AND CARDIOVASCULAR ADAPTATIONS TO DYNAMIC ONE-LEGGED EXERCISE TRAINING. C. A. Ray, W. M. Pace*, and M. P. Clary*. Univ. of Iowa, Iowa City, IA 52242.

The purpose of the present study was to determine the effect of exercise training on sympathetic and cardiovascular responses to exercise. Six men were trained using high-intensity interval and prolonged continuous one-legged cycling 4 day/wk, 40 min/day, for 6 wk. Heart rate (HR), mean arterial pressure (MAP), and muscle sympathetic nerve activity (MSNA; peroneal n.) were measured during 3 min of submaximal upright dynamic one-legged knee extensions at 40 W before and after training. After training, peak oxygen uptake in the trained leg increased 19±2% ($p < .01$). MSNA and cardiovascular results before and after training are presented as mean±SE (*$p < .01$ vs. control; †$p < .01$ vs. before training; §$p = .06$ vs. before training).

		Baseline	EXERCISE 1'	EXERCISE 2'	EXERCISE 3'
MSNA	before	29±3	22±2*	25±3	32±2
(bursts/min)	after	28±1	19±1*	23±1*	22±3*†
HR	before	77±3	96±4*	103±4*	108±5*
(bpm)	after	71±6†	89±5*†	94±4*†	96±5*†
MAP	before	91±7	111±7*	123±7*	132±8*
(mmHg)	after	91±11	104±7*	113±5*§	119±4*†

Responses to exercise in untrained subjects were not different at 0 and 6 wk. These results indicate 1) exercise training prolonged the decrease in MSNA during leg exercise and 2) training-induced adaptations of heart rate and MSNA are regulated by different mechanisms.

50.3

DIFFERENTIAL EFFECTS OF SYMPATHETIC NERVE STIMULATION ON MUSCLE BLOOD FLOW DURING CONTRACTIONS OF HIGHLY GLYCOLYTIC VERSUS HIGHLY OXIDATIVE RAT SKELETAL MUSCLE. Gail D. Thomas and Ronald G. Victor. UT Southwestern Med. Ctr., Dallas, TX 75235

Although muscle contraction is well known to reflexly increase sympathetic discharge to skeletal muscle, the effects of this sympathetic discharge on muscle blood flow remain controversial. In quiescent rat skeletal muscle, CO_2-induced acidosis attenuates alpha-adrenergic vasoconstriction. We therefore hypothesized that in contracting skeletal muscle increased glycolytic flux with lactic acidosis also might attenuate sympathetically-mediated vasoconstriction. In 11 anesthetized rats, we compared effects of lumbar sympathetic nerve stimulation (5v,5Hz) on mean arterial pressure (MAP) and femoral blood flow (FBF, Doppler velocimetry) to both hindlimbs at rest and during unilateral intermittent contractions of either the slow-oxidative soleus or fast-glycolytic gastrocnemius muscles. At rest, sympathetic stimulation increased MAP by 24±4 mmHg and decreased FBF by 30±4%. During contractions of the soleus these sympathetically-mediated responses were well preserved, whereas during fatiguing contractions of the gastrocnemius the blood pressure response to lumbar nerve stimulation was well preserved but the vasoconstrictor response in the contracting hindlimb was abolished: FBF did not decrease but rather increased passively, by 61+16% ($p<.05$), with the increase in blood pressure. This loss of sympathetically-mediated vasoconstriction occurred only in the contracting hindlimb and was not evident in the contralateral resting hindlimb of the same rats. We conclude that muscle contraction indeed can impair the normal ability of sympathetic nerves to evoke vasoconstriction in the skeletal muscle bed and suggest that this impairment is caused by a local action of H+ or other glycoltic metabolites on vascular smooth muscle.

50.4

INCREASE IN RENAL SYMPATHETIC NERVE ACTIVITY IN RESPONSE TO DYNAMIC EXERCISE IS INTENSITY-RELATED. K.P. O'Hagan, S.W. Mittelstadt, L.B. Bell and P.S. Clifford. Medical College of Wisconsin and VA Medical Center, Milwaukee, WI 53295.

In rabbits, renal sympathetic nerve activity (RSNA) increases at the onset of dynamic exercise. We asked if the initial rise in RSNA was related to the intensity of exercise, and whether RSNA remained elevated as exercise continued. Renal nerve recording electrodes were implanted in 10 rabbits 2 days prior to study. Heart rate (HR), blood pressure (BP) and RSNA were monitored. Two treadmill protocols were used: 12 m/min for 2 min; 7 m/min for 5 min. Increases in HR, BP and RSNA in response to 2 min of exercise were intensity-related, as shown below (mean±SE: *=P<0.05 from 7 m/min)

	(m/min)	REST	EXERCISE TIME MIN1	MIN2	MIN5
HR	7	218±9	Δ39±6	Δ52±7	Δ65±8
(b/min)	12	215±9	Δ50±7*	Δ71±8*	
BP	7	72±2	Δ7±1	Δ9±1	Δ9±2
(mmHg)	12	71±3	Δ11±2*	Δ13±2*	
RSNA	7		Δ72±10	Δ49±9	Δ54±13
(Δ%)	12		Δ107±17*	Δ83±22*	

Peak levels of RSNA were observed in the first 10 sec of exercise, at both 7 and 12 m/min. RSNA then stabilized at lower but still elevated values as BP and HR reached steady-state levels through 5 min of exercise at 7 m/min. These data demonstrate that the increase in sympathetic drive to the renal bed during treadmill exercise is intensity-related, and RSNA remains elevated through at least 5 min of submaximal dynamic exercise. Supported by NIH and VA Medical Research Service.

50.5

CIRCADIAN PATTERNS IN SYMPATHOADRENAL AND PRESSOR REACTIVITY TO EXERCISE IN HEALTHY MEN OCCUR INDEPENDENT OF BASELINE PATTERNS. Matthew S. Hickey, David L. Costill, Matthew D. Vukovich, and Krystof Kryzemenski*. Human Performance Laboratory, Ball State University, Muncie, IN 47306.

In an attempt to investigate circadian patterns in sympathoadrenal and pressor reactivity to exercise, 8 competitive male cyclists (age= 23.8±0.5 yr, VO_2max= 4.68±0.8 L·min^{-1}) performed bouts of static (ST) and dynamic (DYN) exercise at 0600-0700h (AM) and at 1600-1700 (PM). The ST protocol utilized a 2 leg isometric contraction on a leg press apparatus at 30% MVC until failure, and was monitored by a strain gauge interfaced with a PC. HR, MAP, NE, and EPI responses were recorded preexercise, at 2 min, and at failure. The DYN protocol involved stationary cycling for consecutive 6 min periods at 60% and 85% of VO_2max. HR, MAP, EPI, and NE were recorded preexercise and at each workload. No differences were observed in preexercise or exercise HR under any condition. Total accumulated work and time to failure in ST were not different in AM vs PM. No differences were observed in preexercise MAP under any condition, and the MAP response to DYN was not different in AM vs PM. MAP was significantly ($P<0.01$) higher in ST-PM at 1 min, 2 min, and at failure vs ST-PM. Moreover, this difference (+8 mm Hg, +5.5%) was constant despite a continued increase in MAP over time, and was attributable to changes in both systolic and diastolic pressure. Preexercise EPI and NE were higher ($P<0.01$) in AM under all conditions. Absolute exercise levels were not different in ST or DYN, but the % change from baseline was significantly ($P<0.01$) higher in ST-PM for EPI (+170%PM vs +38%AM) and NE (+284%PM vs +178%AM). Additionally, the EPI response to DYN-PM was significantly ($P<0.05$) higher at 60% (+45%PM vs +7.5%AM) and at 85% VO_2max (+47%PM vs +23.7%AM). These data support a circadian pattern in sympathoadrenal and pressor reactivity to exercise that is dependent on the type of exercise but independent of the baseline circadian patterns.

50.6

URINARY CATECHOLAMINE LEVELS DURING THREE WEEKS ACCLIMATIZATION TO 4,300 M. R.S. Mazzeo, G.A. Brooks, G.E. Butterfield, D.A. Podolin, M.E. Selland*, E.E. Wolfel, and J.T. Reeves. University of Colorado, Boulder, CO 80309.

The sympathoadrenal system plays a major role in adjustments to both acute and chronic high altitude exposure. Thus, this study investigated 24 hr urinary catecholamine excretion during 3 wks exposure to 4,300 m in control and β-blocked subjects. Eleven healthy, sea level resident males (26±1 yrs) were studied under resting conditions at sea level (SL), on arrival and during 21 days at 4,300 m (Pikes Peak). Six subjects received 240 mg/day propranolol (P) while 5 were given a placebo (C). Urinary norepinephrine excretion (NE) did not differ between groups while at SL (38.7±4.3 v 32.4±2.8 μg/day for C and P, respectively). Norepinephrine levels increased significantly ($p<0.05$) during altitude exposure reaching peak values on day 6-7 (105.5±16.1 v 88.4±12.3 μg/day for C and P, respectively). Values for P were consistently lower than those observed for C. Epinephrine (EPI) excretion increased with initial exposure when compared to SL (4.6±0.6 to 6.6±0.6 for C, 4.7±0.5 to 6.7±1.0 μg/day for P), however, no consistent pattern was observed for the following 20 days at altitude. No differences in urinary EPI were observed between groups at any time. Resting arterial NE levels as well as net NE release across the leg confirm the elevation in sympathetic activity with acclimatization and suggest that resting muscle is a major source of blood and urinary NE. Increased urinary NE excretion correlated with changes in minute ventilation, $P_{ET}CO_2$, and blood volume. It remains to be determined if these variables are regulated by or regulate sympathetic activity.

50.7

CHOLINE CITRATE MAY ENHANCE ATHLETIC PERFORMANCE. B.W. Sandage, Jr., Ph.D.*, L. Sabounjian*, R. White*, R.J. Wurtman. IPI, Lexington, MA 02173 and MIT, Cambridge, MA 02139.

Plasma choline levels have been shown to influence the amounts of acetylcholine released by brain and motor neurons, such as those used in running. Long distance running has been shown to decrease plasma choline levels, and that decrease has been blocked by giving choline. Ten long distance runners (8M/2F) participated in a randomized, double-blind, placebo-controlled, crossover study comparing the effects of choline citrate (CC) to placebo in its ability to diminish muscle fatigue and thereby affect athletic performance during and following strenuous exercise. Each runner received either CC (2.8g) or placebo 1 hour prior to and again after completing 10 miles of a 20 mile run. Runners were crossed-over one month later. Run time and a battery of measurements assessing muscle strength and fatigue were conducted at baseline, immediately post-run and at 1.5 hours post-run. Plasma samples for choline measurements were collected at 0, immediately post-run, 1.0, 1.5 and 2.0 hours post-run. The mean run time was found to be significantly ($p<0.05$) shorter when the runners had consumed CC. Plasma choline levels were raised following CC but dropped in those runners who did not receive CC. No other differences were noted. CC administered prior to strenuous exercise will block the fall in plasma choline and may improve athletic performance.

50.8

HEART RATE AND PLASMA CATECHOLAMINE RESPONSES TO FLIGHT IN PIGEONS

Wenjing Liang* and Steven P. Thomas, Dept. Biol. Sciences, Duquesne Univ., Pittsburgh, PA 15282.

We have measured heart rates (HR) and plasma catecholamine titers [norepinephrine (NE), epinephrine (E) and dopamine (DA)] of pigeons (Columba livia) during quiet rest (QR), pre-flight (PF) and steady-state wind tunnel flight (SF). Blood samples were obtained from the right atrium via a jugular vein catheter, and were analyzed for catecholamines via a radioenzymatic assay (CAT-A-KIT). Mean values (and SD) are summarized below:

	HR b/min.	NE ng/ml	E ng/ml	DA ng/ml
QR	119.4(44)	0.272(0.16)	0.055(0.02)	0.029(0.01)
PF	282.9(67)	1.026(0.78)	0.198(0.09)	0.086(0.02)
SF	663.2(15)	10.276(2.2)	1.002(0.36)	0.282(0.17)

The (SF/QR) ratios of our pigeons are at least 6x (for NE), or at least 5x (for E) greater than corresponding (strenuous exercise/rest) catecholamine ratios reported for dogs and humans. These dramatic increases in plasma catecholamines, especially NE, indicate that pigeons utilize powerful sympathoadrenal responses to help satisfy their high energy requirements of flight.

50.9

LEFT VENTRICULAR RESPONSES TO SUSTAINED MAXIMUM DEADLIFT EXERCISE DURING ACUTE BETA-BLOCKADE IN NORMAL MEN. Peter B. Slane*, Peter Hanson, Peter S. Rahko. University of Wisconsin Medical School, Madison, WI 53792

Isometric deadlift (DL) exercise performed in standing position produces a pressor increase in arterial blood pressure mediated by increases in heart rate and cardiac output. These responses are directly related to the intensity of the lift. Continuous measurement of left ventricular (LV) performance during DL has shown that LV contractile indices decline initially but are restored by Frank-Starling mechanisms. Upon release of DL, there is a marked increase in ejection fraction (EF) and systolic pressure / end-systolic volume ratio (SP/ESV) accompanied by a rapid decrease in arterial pressure. We evaluated the potential contribution of B-adrenergic mechanisms in 5 normal subjects during control (C) DL and after acute B-blockade (BB) with Esmolol. LV performance was continually monitored by 2D Echocardiography (apical 4 chamber view) and MAP via brachial artery catheter. DL was performed on a force platform at 100% maximum for 30s. Esmolol, 100mg, was infused IV 5 min prior to repeat DL.

	Rest		DL 30 s		Rec (5s)	
	C	BB	C	BB	C	BB
HR min-1	78±10	80±10	125±15	119+14	118±19	115±16
MAP mmHg	106±5	99±4*	161±13	140±6*	70+10	68±6
SV ml	50±10	47±5	44±14	43±11	36+13	35±15
EF %	58±5	54±8	59±10	47±8	83+8	66±8*
SP/ESV	4.3±2	3.5±1	7.9±2	3.9±1*	15.2±3	6.4±4*

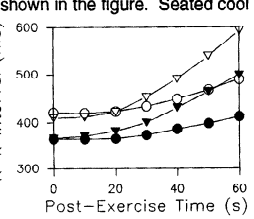
(mean +/- (1SD), * =p <.05, C vs. BB)

At rest, BB produced a significant reduction in MAP, but all other parameters were unchanged. During maximal DL, SP/ESV and MAP were significantly attenuated and EF was decreased but not sig. With early recovery, both SP/ESV and EF were significantly reduced by BB, while MAP, HR, and SV were unaffected. These responses indicate that LV performance during maximal DL is maintained primarily by Frank-Starling mechanisms and the hyperdynamic increases in LV indices which occur in early recovery are mediated by augmented B-adrenergic drive. Chronotropic control of heart rate appears to be regulated independently under these conditions.

50.10

EFFECT OF COOL DOWN AND β-BLOCKADE ON POST-EXERCISE HEART RATE CHANGES. Alison R. Graves*, Marco E. Cabrera, Michael L.Smith. Case Western Reserve Univ. Cleveland,OH 44106.

The changes in autonomic control of the heart during and immediately following exercise are unclear. In addition, the effect of an active cool down on post-exercise autonomic control of heart rate (HR) is unknown. Our objectives were to determine 1) the sympathetic contribution to post-exercise control of HR and 2) the difference between an active cool down (100W) and a seated cool down on post-exercise autonomic control of HR. *Methods:* Heart rate and respiration were measured continuously during ramped exercise to a peak workload above ventilatory threshold. A 2x2 design was used in which the exercise protocol was repeated with and without an active cool down and with and without cardioselective β-blockade (metoprolol, 0.1 mg/kg). The order of studies was randomized. *Results:* The post-exercise HR changes during cool down [active (circles); seated (triangles)] and β-blockade [with (open); without (solid)] are shown in the figure. Seated cool down resulted in a faster return of HR than active cool down and this effect was unaffected by cardiac sympathetic blockade (slope of response between control and β-blockade were not different, $p>0.05$). *Conclusions:* These data suggest that the withdrawal of sympathetic effects on HR is minimal during the initial period of recovery regardless of the type of cool down.



50.11

INFLUENCE OF AGING ON THE HEMODYNAMIC ADJUSTMENTS TO GRADED EXERCISE IN THE RAT. K.C. Kregel. Department of Exercise and Sport Sciences, University of Arizona, Tucson, AZ 85721.

The purpose of this study was to determine whether the regional and systemic hemodynamic adjustments to graded treadmill exercise are altered with advancing age. Mature (MAT, 12 mo) and senescent (SEN, 24 mo) male Fischer 344 rats were instrumented with an arterial catheter and Doppler flow probes, and mean arterial pressure (MAP), heart rate (HR), and superior mesenteric (MF) and iliac (IF) blood flow velocities were determined during graded exercise to exhaustion. Maximal oxygen consumption was significantly reduced in the SEN compared to the MAT rats (62 ± 3 vs. 71 ± 3 ml·min^{-1}·kg^{-1}). Values presented are changes from resting control to the end of peak exercise (i.e., exhaustion):

	ΔMAP (mmHg)	ΔHR (bts/min)	ΔMF (%)	ΔMR (%)	ΔIF (%)	ΔIR (%)
MAT	19 ± 5	171 ± 7	-38 ± 3	87 ± 10	91 ± 12	-35 ± 3
SEN	16 ± 2	144 ± 7*	-46 ± 3*	125 ± 11*	80 ± 10	-32 ± 4

(* = P <0.05 vs. MAT; n = 9 - 10 per group; MR and IR = calculated mesenteric and iliac vascular resistance, respectively)

These findings indicate that the regulation of arterial blood pressure and hindlimb vascular resistance is not altered with advancing age, while splanchnic resistance is exaggerated in senescent compared to mature Fischer 344 rats during exhaustive treadmill exercise. It is concluded that the blunted tachycardia during intense dynamic exercise in older rats may necessitate a compensatory increase in visceral vasoconstriction in order to properly augment arterial blood pressure and skeletal muscle blood flow.

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50.12

EFFECTS OF CHRONIC PHYSICAL ACTIVITY ON SYMPATHETIC NERVE ACTIVITY IN OLDER ADULT HUMANS. Alexander Y. Ng, Robin Callister*, Mary Jo Reiling*, and Douglas R. Seals. University of Arizona, Tucson, AZ 85721

Aerobic exercise training does not affect resting muscle sympathetic nerve activity (MSNA) in younger adults (*Acta Physiol Scand* 120:499, 1984; *Hypertension* 17:36, 1991), a population with relatively low MSNA at rest. MSNA at rest, however, is markedly elevated in older healthy adults (*Circ. Suppl.* 84: II-317, 1991). Thus, our present aim was to test the hypothesis that chronic aerobic exercise results in a lowered resting MSNA in healthy older adults. During supine rest, MSNA (peroneal microneurography), heart rate (HR) and arterial blood pressure (AP), were measured in 12 master athletes (MA, 65±1 yr, X±SE) involved in cycling or running and in 10 healthy normotensive, but untrained, controls (UT, 65±1 yr). There were no differences in height or weight between MA and UT. MA had less body fat and expended more energy daily than UT (19±1 vs 23±1%; 45±1 vs 36±1 kcal/kg/day; $p<0.05$). There were no significant differences between MA and UT in mean AP (89±2 vs 89±1 mmHg) or MSNA burst frequency (39±3 vs 33± 4 bursts/min). However HR was lower and MSNA burst incidence higher in MA compared to UT (55±2 vs 62±2 bts/min; 71±5 vs 53±6 bursts/100 heart bts). Our results do not support the hypothesis that vigorous regular aerobic exercise attenuates the age-related rise in MSNA at rest in healthy, normotensive humans.

Supported by NIH grants AG0537, AG00423 and AG05518

50.13

SYMPATHETIC NERVE ACTIVITY AT THE ONSET OF LEG-CYCLING EXERCISE. Robin Callister, Alexander V. Ng and Douglas R. Seals. University of Arizona, Tucson, AZ 85721

A "mass sympathetic discharge" is thought to occur at the onset of large-muscle dynamic exercise (Guyton, 1986) which is responsible for vasoconstriction in several regions allowing a redistribution of cardiac output to active muscle while maintaining arterial perfusion pressure to vital organs. An increase in sympathetic nerve activity to non-active skeletal muscle (MSNA) is considered an important part of this response. To test this hypothesis, MSNA (radial nerve microneurography) was measured before and during two-leg cycling exercise at 33W (n=11), and at multiple workloads up to 200W (n=4) or above. Immediately prior to exercise, MSNA decreased to 20% of control levels. With the initiation of exercise, MSNA rose to 60% of control but remained below control levels throughout the first minute of exercise. This pattern of activity was observed in workloads up to 60% of maximum. Above this intensity, MSNA tended to increase above control levels by the end of the first minute of exercise but the same general pattern of response (decrease in MSNA prior to initiation, and small elevation in MSNA on initiation of cycling) was observed even at *maximum* exercise levels. These data do not support the hypothesis that MSNA increases at the onset of large-muscle dynamic exercise. In contrast, they suggest that MSNA is markedly reduced during the initiation of exercise, possibly contributing to vasodilation in both active and non-active skeletal muscle.

Supported by NIH grants HL39966, AG06537 and AG00423.

50.14

THE EFFECT OF LOWER BODY POSITIVE PRESSURE ON EXERCISE CAPACITY OF SPINAL CORD INJURED INDIVIDUALS. Kenneth H. Pitetti and P.J. Barrett *, Wichita State University, Wichita, Kansas 67208

The purpose of this study was to determine if lower body positive pressure (LBPP) applied by means of an anti G-suit could improve cardiovascular parameters of spinal cord injured individuals (SCII) during arm crank exercise. Ten SCII (8 quadriplegics, 2 paraplegics) healthy males (31.1±10 years) and 4 non-disabled (ND) males (age 34±9 years) participated in this study. A discontinuous arm crank exercise test to determine peak cardiovascular capacity was performed with and without LBPP. For the SCII, significantly higher peak oxygen consumption (VO2; 1042±212 vs 839± 218 ml/min), ventilation (VE; 46±17 vs 35±9 l/min) and work level (50±15 vs 40± 13 watts) were seen during LBPP. No significant differences for peak VO2, VE, or work level were seen for the ND subjects. Significantly higher submaximal mean arterial blood pressures and lower submaxial heart rates were seen for the SCII but not for the ND subjects. Cardiac output (Q, l/min; CO2 rebreathing method) was measured at 50% peak VO2 with and without LBPP. SCII demonstrated higher Q (8.8±2.2 vs 8.3±2.5 l/min), stroke volume (94±20 vs 84±20 ml), and mean arterial blood pressure (80±14 vs 71±13 mm Hg) with LBPP while ND subjects demonstrated higher mean arterial blood pressure with LBPP. The results suggest that LBPP limited the pooling of blood in the lower extremities for SCII thus providing more central blood volume.

50.15

45 TORR LOWER BODY POSITIVE PRESSURE INCREASES RESTING BLOOD PRESSURE. C.G. Crandall, J.W. Williamson, J.T. Potts, X. Shi*, P.B. Raven. Texas College of Osteopathic Medicine, Fort Worth, TX 76107.

Six men were serially exposed for three minutes to combinations of super-systolic leg occlusion (LO) and +45 torr lower body positive pressure (LBPP) to determine the factors involved in LBPP induced blood pressure elevations. During each stage, heart rate (HR), intra-arterial pressure (MAP), central venous pressure (CVP), and stroke volume (SV) via continuous wave Doppler were obtained. Cardiac output (Q_C = HR * SV) and total peripheral resistance (TPR = MAP / Q_C) were calculated during each measurement period. Results (mean ± sem) are summarized below.

	Control	LO	LO LBPP	LBPP	LO LBPP	LO	Recovery
MAP	80.0±1.9	83.1±1.3	88.2±1.4*	86.9±1.9*	88.1±1.9*	83.8±2.0	81.5±1.5
HR	63.5±5.6	62.7±5.5	64.3±4.8	61.5±5.8	59.7±4.9	62.5±7.1	64.6±5.2
CVP	5.9±0.7	5.9±0.7	9.9±0.9*	10.6±0.6*	10.2±0.4*	5.8±0.3	5.9±0.3
TPR	16.4±1.0	16.4±1.3	16.4±1.6	14.9±1.0	16.5±0.6	15.7±1.0	12.5±0.2
Qc	4.88±0.4	5.12±0.5	5.52±0.6	5.94±0.6	5.38±0.4	5.36±0.5	6.86±0.3

*p ≤ 0.05 from control (LO: leg occlusion, LBPP: lower body positive pressure)

The pressor response to LBPP is not a result of peripheral translocation of blood because it occurs when movement of blood is prevented with LO. We suggest that LBPP at rest may stimulate a neurogenic mechanical reflex in the legs resulting in a rise in blood pressure while preventing the expected baroreflex induced bradycardia.

Supported by HL43202

50.16

HEMODYNAMIC RESPONSES OF HIGH-FIT RUNNERS DURING HEAD-UP TILT TESTING TO SYNCOPE. T.J. Ebert and T. Denahan. Medical College of WI and VA Medical Center, Milwaukee, WI 53295

This study explored the moment-to-moment response of 7 endurance-trained (ET) runners (VO2max=66 ± 2 ml/kg/min) and 5 sedentary (SED) subjects (VO2max=39 ± 3 ml/kg/min) during 30 min of 70° head-up tilt (HUT) testing. Written informed consent was obtained from each subject prior to experimental procedures. HR, BP (radial artery), central venous pressure (CVP, jugular vein), stroke volume (SV, impedance cardiography), forearm vascular resistance (FVR, Hg-in-Silastic forearm plethsmography), calculated cardiac output (CO) and systemic vascular resistance (SVR) were measured before and continuously during HUT. Supine resting HR was lower (52±5 vs 66±3 beat/min, p<0.05) and SV higher (162±19 vs 97±14 ml, p<0.05) in ET versus SED subjects. Immediate response (1st min) to HUT revealed a larger decrement in SV (-81±15 vs -46±12 ml) in ET runners but similar increases in HR, FVR and SVR. All ET subjects fainted: mean time to syncope was 10.5 ± 2.25 min (range=4.5-19.0 min). ET responses preceding syncope consisted of a failure to maintain SVR and FVR compared to SED (p<0.05) leading to a gradual decline in BP while HR continued to rise. Relative bradycardia in ET only occurred immediately prior to syncope. ET runners appear to be more susceptible to syncope during orthostatic stress; syncope is associated with an early failure of sympathetically-mediated vasoconstriction. The sudden vagally-mediated bradycardia described in the "vasovagal" response only occurs immediately prior to onset of syncope.

50.17

NONORTHOSTATIC AUTONOMIC STRESS RESPONSES DO NOT DISTINGUISH BETWEEN HIGH-FIT RUNNERS WITH SYNCOPE AND SEDENTARY, NONSYNCOPAL SUBJECTS. T. Denahan and T.J. Ebert. Medical College of WI, Milwaukee, WI 53226

Long-term endurance training (ET) has been proposed to result in altered autonomic reflexes which predispose high-fit individuals to syncope. We identified a group (n=7) of ET runners (VO2max=66 ± 2 ml/kg/min) with syncope during head-up tilt testing and a group (n=5) of sedentary subjects (SED, VO2max=39 ± 3 ml/kg/min) without syncope during tilt. After informed consent, subjects were instrumented for HR, BP (radial artery), central venous pressure (CVP, jugular vein) and muscle sympathetic nerve activity (MSNA, peroneal nerve). Measurements were recorded before and during a 3-min isometric handgrip (IH), a 60-sec cold pressor (CP) and sequential infusions of nitroprusside (NIP). At rest, HR was lower in ET vs SED (52 ± 5 vs 66 ± 3, p<0.05) while resting BP (~90 mmHg), CVP (~6 mmHg) and MSNA (~30 bursts/100 heart beats) did not differ between groups.

Peak Responses (Δ) to Autonomic Stresses (X±SEM)

Test	group	HR, b/min	Mean BP, mmHg	CVP, mmHg	MSNA, bursts/100 heart beats
IH	SED	21 ± 7	24 ± 3	0.3 ± 0.8	9 ± 8
	ET	11 ± 1	20 ± 4	1.8 ± 0.4	7 ± 2
CP	SED	6 ± 5	15 ± 3	0.6 ± 0.6	-3 ± 2
	ET	2 ± 2	18 ± 4	1.2 ± 0.7	5 ± 3
NIP	SED	21 ± 2	-9 ± 2	-4.0 ± 0.8	23 ± 7
	ET	13 ± 4	-4 ± 1	-2.4 ± 0.6	25 ± 7

Autonomic responses did not differ between ET and SED subjects despite marked intolerance to tilt in the ET group. Thus, autonomic testing in the supine position does not identify athletes at risk for syncope.

50.18

EFFECT OF EXERCISE ON ORTHOSTATIC RESPONSE FOLLOWING SIMULATED WEIGHTLESSNESS. J.D. Seelbach, J.E. Cribb*, G.K. DeJong, and J.E. Davis. Department of Exercise & Health Science, Alma College, Alma, MI 48801

The effects of exercise on orthostatic response were studied after five days of simulated weightlessness at 6° head down tilt (HDT) in three groups (6 per group) of males (mean age = 21.4 yr ± SE 1.0). A control group (C) was subjected to 5 days of HDT with no intervention, a second group (E) exercised for 90 minutes per day, while a third group (E+F) exercised for 90 minutes per day and ingested 1 liter of isotonic saline solution 2 hours prior to the conclusion of bedrest. All subjects underwent progressive (0 to -50 mm Hg) lower body negative pressure (LBNP) trials before (PRE) and after (POST) 5 days of HDT. Heart rate, blood pressure, forearm blood flow, calf circumference, and stroke volume were measured during LBNP. Systolic blood pressure decreased during all LBNP tests with no differences observed between groups. Heart rate increased during all LBNP trials with results (mean ± SE) as follows:

	PRE			POST		
	C	E	E+F	C	E	E+F
0mm Hg	68 ± 3	62 ± 2	65 ± 2	66 ± 2	56 ± 2	64 ± 2
50mmHg	87 ± 3	78 ± 2	78 ± 5	106 ± 8	89 ± 5	83 ± 5

The HR increase during LBNP POST HDT was significantly greater in the C group than in either E or E+F. The ability to regulate blood pressure in response to an orthostatic challenge appeared not to be compromised as a result of simulated weightlessness. However, these data would suggest that blood pressure regulation in the control group was achieved to a greater extent by increasing HR than for either of the exercise groups. Exercise appeared to minimize the cardiovascular stress associated with orthostasis after weightlessness.

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50.19

CARDIAC AFFERENTS ATTENUATE THE MUSCLE CHEMOREFLEX IN RATS. Stephen E. DiCarlo and Heidi L. Collins*, Northeastern Ohio Universities College of Medicine, Rootstown, Ohio 44272.

The influence of cardiac afferents on the muscle chemoreflex (MR) was examined in 9 rats. Rats were instrumented with a silastic-tipped catheter inserted into the pericardial space. Two weeks later, a Doppler ultrasonic flow probe and a pneumatic vascular occluder were positioned around the terminal aorta. Finally, a teflon catheter was placed in the carotid artery for the measurement of mean arterial pressure (MAP) and heart rate (HR) and a silastic-tipped catheter was placed in the right atrium via the jugular vein to obtain blood samples. The hemodynamic responses to a reduction in terminal aortic blood flow velocity (TAQ) during exercise were examined under 3 conditions: 1) control (C), 2) cardiac efferent blockade (Ex), and 3) combined cardiac efferent and afferent blockade (Ax). Exercise (9 meters/minute, 10% grade) increased HR (68 ± 14 bpm), MAP (12 ± 2.0 mmHg) and TAQ (6 ± 1.0 kHz). During exercise, a reduction of TAQ reduced mixed venous Po_2 17 ± 5%. The table presents the means ± SE for the changes in TAQ, MAP, and HR during the occlusion. The gains of the MR are also presented.

	C	Ex	Ax
TAQ (Δ%)	-10.8 ± 1.0	-12.5 ± 1.3	-12.6 ± 1.6
MAP (mmHg)	12.6 ± 1.3	5.8 ± 0.8	15.4 ± 2.4
HR (bpm)	46.7 ± 12.1	13.3 ± 7.2	21.1 ± 6.4
Gain (mmHg/%)	1.3 ± 0.2	0.6 ± 0.06	1.5 ± 0.3

Ex reduced the gain of the MR -56 ± 6%. However, Ax increased the MR gain 196 ± 47%. Thus cardiac afferents tonically inhibit the pressor response to reductions in TAQ during exercise. (Supported by HL 45245)

50.20

PERIPHERAL AND CENTRAL CHEMOREFLEXES OPERATE SIGNIFICANTLY BELOW THE THRESHOLD FOR ACTIVATION IN HEALTHY HUMANS. Michael L.Smith, Michael J. Decker, Kingman P. Strohl, Case Western Reserve University. Cleveland, Ohio 44106.

Activation of peripheral (hypoxic stimulus) and central (hypercapnic stimulus) chemoreflexes are known to produce autonomic-mediated pressor effects. However, the normal function of these chemoreflexes is not well defined. ***Purpose:*** We sought to determine the stimulus-response relation near the baseline operational point of peripheral and central chemoreflex control of sympathetic nerve activity during transient, acute activation of each chemoreceptor population. ***Methods:*** Oxygen saturation (SaO_2), end-tidal P_{CO2}, heart rate, blood pressure, and muscle sympathetic nerve activity were measured continuously during transient (10-20 sec) oxygen desaturation (1-3 breaths of 90-100% N_2) or CO_2 retention (2-8 breaths in a bag) in 6 volunteers (age = 20-39 yrs). Each stimulus was repeated 6-8 times to produce a range of stimuli (70-90% SaO_2 and 4-25 mmHg end-tidal ΔP_{CO2}). ***Results:*** Sympathetic nerve activity was predictably low in this healthy population (15±4 bursts/100 heartbeats). Sympathetic nerve activity increased only when SaO_2 fell below 75-78% or P_{CO2} increased more than 12-15 mmHg. No evidence of saturation kinetics was observed in the range of stimuli given. ***Conclusion:*** These data suggest that both peripheral and central chemoreceptors operate significantly below the threshold for activation in healthy humans.

50.21

HINDLIMB MUSCLE CONTRACTION ELICITS DEPRESSOR RESPONSES IN ANESTHETIZED RATS. J. M. Overton and R. W. Stremel. Exercise Physiology Program and Department of Physiology and Biophysics, University of Louisville, Louisville, KY 40292.

The purpose of these experiments was to determine the hemodynamic responses to static muscle contraction elicited by ventral root stimulation in anesthetized rats. Sprague Dawley rats were anesthetized with α-chloralose/urethane and instrumented with carotid, jugular and tracheal catheters and pulsed Doppler flow probes on the mesenteric and femoral arteries. The lumbar ventral roots were isolated after a L4-S1 laminectomy. The cut ends of rootlets innervating hindlimb muscles were stimulated (60 Hz, 0.1 msec duration) at 2-8X motor threshold for 30 seconds. Isometric contraction of the left triceps surae produced increases in tension of 175-375 grams. This elicited a rapid reduction in arterial pressure of 15-35 mm Hg. The peak depressor response occurred 5-8 seconds after initiation of contraction. Blood pressure remained depressed throughout the hindlimb contraction. During contraction heart rate increased slightly (5-15 beats/min) and mesenteric blood flow decreased (4-9%). The results indicate that the hemodynamic response pattern elicited by static muscular contraction in anesthetized rats is disparate from that elicited by dynamic exercise in conscious rats. Supported by Amer. Heart Assoc., KY Affiliate and NIH 06296.

50.22

AORTIC BARORECEPTOR-HEART RATE REFLEX RESPONSE TO HYPOTENSION: EFFECT OF FITNESS. X.Shi, C.G.Crandall, J.T.Potts, J.W.Williamson, B.H.Foresman, & P.B.Raven, Department of Physiology, Texas College of Osteopathic Medicine, Fort Worth, TX 76107.

In seven average fit (AF) men, aged 28±1.2 years, and five high fit (HF) men, aged 26±1.3 years, we compared their heart rate (HR) reflex response during sodium nitroprusside (SN) induced hypotension. Fitness level was assessed by determining maximal oxygen uptake ($VO2_{max}$) on a treadmill. $VO2_{max}$'s were 45.7±0.8 and 63.5±1.6 ml/kg/min in the AF and HF subjects, respectively, $p<0.001$. Steady state SN infusion decreased mean intra-radial arterial pressure (MAP) by 13 mmHg in both groups, however, the increases in HR were significantly ($p<0.05$) less in the HF (15.7±4.0 bpm) than the AF (24.2±2.8 bpm). When neck suction (NS) was applied to counteract the decreased carotid sinus transmural pressure during steady state SN infusion, thereby isolating the aortic baroreceptors, the increased HR of the HF subjects averaged 6.9±2.8 bpm and in the AF subjects averaged 16.6±2.7 bpm, $p<0.02$. The calculated gains (from the ratio of the changes in HR to MAP) listed below:

		AF	(%)	HF	(%)	p value
SN	(bpm/mmHg)	2.0±0.3	(100)	1.2±0.2	(100)	0.05
SN+NS	(bpm/mmHg)	1.3±0.3	(65)	0.5±0.1	(37)	0.02
Diff.	(bpm/mmHg)	0.7±0.2	(35)	0.7±0.1	(63)	N.S.

Diff. = SN minus SN+NS.

These data suggest that the aortic baroreceptor-HR reflex is less responsive in the HF than the AF subjects.

(supported in part by NIH grant #HL43202)

50.23

ATTENUATED CARDIOPULMONARY BAROREFLEX SENSITIVITY AFTER EXERCISE-INDUCED BLOOD VOLUME EXPANSION IN HUMANS. C.M. Gillen*, T. Nishiyasu*, C.A. Weseman*, G.L. Langhans*, G.W. Mack, and E.R. Nadel. J.B. Pierce Lab. and Yale Univ. Sch. of Med., New Haven, CT 06519.

To test the hypothesis that reduced cardiopulmonary (CP) baroreflex sensitivity is a direct result of exercise, we measured forearm vascular conductance (FVC) responses to reduced central venous pressure caused by graded administration of lower body negative pressure (LBNP) at 2, 20 and 44 h recovery (rec) from intense exercise and during AM and PM controls. Blood volume (BV; calculated from hematocrit and hemoglobin) was unchanged from control 2 h after exercise (32 min of exercise at 85% VO_2max) and increased by 3.5 ± 0.7% and 3.9 ± 1.0% at 20 and 44 h rec ($p<0.01$). At 20 h rec, resting mean arterial pressure (MAP) and cardiac output were increased by 6 ± 1 mmHg and 0.6 ± 0.2 L/min ($p<0.05$). Heart rate and stroke volume (impedence cardiography) responses to LBNP after exercise were not different from control. The reduction in FVC (venous occlusion plethysmography) was significantly less ($p<0.05$) at 2, 20 and 44 h rec during several LBNP periods. Thus, exercise itself directly attenuates CP baroreflex function, because a decrease in the FVC response to LBNP preceded BV expansion. To test the hypothesis that volume-sensitive control of renal function is also attenuated by intense exercise, we measured plasma hormone concentrations and renal output. With BV expanded and MAP increased at 20 h rec, the expected decrease in resting plasma aldosterone concentration and increase in overnight sodium clearence did not occur. However, with BV expanded at 44 h rec, plasma aldosterone was decreased by 26 ± 9% ($p<0.05$), and overnight sodium clearence was increased 51 ± 26% ($p<0.05$). Thus, intense exercise elicits a transient attenuation of the aldosterone response to increased BV. We conclude that attenuation of volume-sensitive reflexes participates in the induction of BV expansion by intense exercise. (HL-20634).

50.24

NON-INVASIVE ASSESSMENT OF BAROREFLEX SENSITIVITY IN TRAINED AND UNTRAINED SUBJECTS. F. Schena, R.Grasso*, R. Poltronieri*, A. Cevese*. Istituto di Fisiologia Umana, Università di Verona, Strada Le Grazie 8, I-37134 Verona.

The baroreflex function changes in transition from rest to exercise. The present investigation was aimed at studying possible interferences of endurance training with such changes, by non-invasive techniques. ECG, finger blood pressure (FIN.A.PRES Ohmeda) and respiratory air flow (modified turbine, Sensor Medics) were measured in four healthy sedentary subjects (UNTR) and four endurance trained athletes (TR). Time series of R-R interval (RR), systolic finger pressure (PSYST), and respiratory air flow (RESP) were produced on a beat-by-beat basis. Two records lasting ten minutes were taken during steady-state conditions respectively with the subjects laying down and standing up. A further six minute record was taken while the subjects were exercising on a cycloergometer at 50 watt. FFT-based power spectral analysis of pre-filtered time series (high-pass, linear-phase, -3dB at 0.025 Hz) was performed. Two frequency bands, respectively centered at peak frequency near 0.1 Hz (LF) and at the peak frequency of RESP spectrum (HF) were identified; the limits of the bands were set where the squared coherence function between RR and PSYST was >0.8 and the power of each band was calculated by integration within these limits. An index of baroreflex sensitivity (BRS) was calculated as the mean ratio of the power moduli of RR and PSYST (Robbe et al. Hypertension 10(2), 538-543, 1987). This ratio was calculated only in the LF band, where the phase diagram indicates that PSYST changes lead RR changes, suggesting a baroreflex mechanism. As expected, the mean heart rate was significantly lower in TR than in UNTR. Mean BRS for UNTR and TR was 13.86 ms/mmHg ±2.68 (S.E.) and 17.61±6.3 during laying, 6.60±0.84 and 10.14±3.14 during standing, 1.97±0.57 and 5.26±0.73 during exercise. In all subjects BRS decreased significantly ($P<0.02$). BRS was lower in UNTR in all conditions; however, the difference was significant only during exercise ($P<0.05$). The present results suggest a positive effect of training on the preservation of the baroreflex function during exercise, which is almost suppressed in untrained subjects as attested by very low BRS values.

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50.25

SYMPATHETIC NERVOUS ACTIVITY IS RELATED TO SYSTEMIC ARTERIAL PRESSURE ELEVATION IN MAN AT 4300 m. Eugene E. Wolfel, Mark A. Selland*, Robert S. Mazzeo, and John T. Reeves. Univ. of Colorado Health Sciences Center, Denver, CO. 80262.

Short term residence at high altitude has been shown to be associated with elevations in systemic arterial blood pressure, but the mechanism for this response is unknown. Our hypothesis was that heightened sympathetic activity was responsible for the increase in blood pressure at high altitude. We determined the effect of 3 wks residence at 4300 m on daytime ambulatory blood pressure in 11 healthy, sea level (SL) males, age 26±1yrs. Six subjects were given propranolol, 240 mg/day, (D) and five subjects placebo (C). Recordings were taken at SL, days 1-2 (H-1), 8-10 (H-2), and 17-19 (H-3) at 4300 m. In addition, 24 hr urine collections were obtained for norepinephrine (NE) on the same days as the ambulatory blood pressure recordings. Residence at 4300 m was associated with a significant increase in mean arterial pressure (MAP) in C, while MAP rose initially at H-1 in D with no further increase over 3 wks.

MAP (mmHg)	Sea Level	H-1	H-2	H-3
Placebo (n=5)	82±1	88±3	91±3*	97±6*†
Propranolol (n=6)	77±4	84±1*	81±1	85±3*

(* p<0.05 vs SL; †p<0.05 vs H-1))

24 hr urinary NE increased over time at 4300 m. in both C and D, and there was a correlation between individual MAP and urinary NE in C ($r=0.78$, $p<0.001$) and D ($r=0.52$, $p<0.01$). Thus, sympathetic stimulation plays an important role in the control of systemic arterial blood pressure at high altitude and beta-adrenergic blockade appears to blunt this effect.

50.26

ANTAGONISTS TO SUBSTANCE P AND SOMATOSTATIN MICROINJECTED INTO THE DORSAL HORN ATTENUATE THE EXERCISE PRESSOR REFLEX. Britt Wilson, Tim Wall, and Kanji Matsukawa*. Moss Heart Ctr & Dept. of Physiology, UT Southwestern Medical Center, Dallas, TX 75235

A previous study has shown that microinjecting an antagonist to either substance P (SP) or somatostatin (SOM) into the L_7 dorsal horn region blunts the exercise pressor reflex. The purpose of this study was to determine the effect of microinjecting these antagonists simultaneously into the L_7 dorsal horn region on the reflex cardiovascular and renal sympathetic nerve (RSNA) responses evoked by static contraction and passive muscle stretch. Cats (n=6) were anesthetized with α-chloralose and static muscle contraction was induced by electrically stimulating (3 X MT; 40 Hz; 0.1 msec) the peripheral end of the cut L_7 ventral root. Static contraction and muscle stretch (1 min in duration for each) were performed before and after microinjecting 250 ng (1 μl) of the SP antagonist (D-Pro^2-D-Phe^7-D-Trp^9-substance P) and the SOM antagonist (cyclo(7-amino-heptanoyl-phenylalanyl-D-tryptophyl-lysyl-threonyl-[benzyl])). Prior to injecting the antagonists, static muscle contraction increased mean arterial pressure (MAP) 45±7 mmHg and RSNA 43±8%. These changes were blunted by microinjecting the antagonists as MAP and RSNA increased 24±3 mmHg and 24±6%. In contrast, antagonist administration had no effect on the pressor (35±6 vs 32±6 mmHg) and renal sympathetic (24±5 vs 28±6%) responses to passive muscle stretch. Microinjecting 2% lidocaine into the dorsal horn virtually abolished the reflex responses to muscle stretch as MAP increased 10±7 mmHg and RSNA increased 9±2%. These results support the hypothesis that the release of SP and SOM in the spinal cord plays a role in mediating the cardiovascular and renal sympathetic nerve responses to static contraction, but not passive stretch of skeletal muscle. Furthermore, these data suggest that the release of other neurotransmitters/neuromodulators may play a role in mediating the exercise pressor reflex.

50.27

IS A REFLEX INCREASE IN BLOOD PRESSURE AN IMPORTANT DETERMINANT OF MUSCLE BLOOD FLOW DURING STATIC EXERCISE IN HUMANS? Jim Hansen*, Tage N. Jacobsen* and Ole Amtorp* (SPON: R.G. Victor) Univ. of Copenhagen, Gentofte Hospital and UT Southwestern Medical Ctr., Dallas, Tx 75235.

Previous studies have advanced the hypothesis that during static handgrip (SHG) reflex increases in blood pressure are able to partially offset increases in tissue pressure and thus effectively maintain increases in muscle blood flow during levels of SHG up to 70% of maximal voluntary contraction (MVC). However, this hypothesis is based upon plethysmographic measurements of blood flow to the entire forearm obtained after, not during, the exercise. The aim of this study was to retest this hypothesis by measuring changes in muscle blood flow to a specific muscle group during the actual period of exercise. To accomplish this aim, we measured xenon washout from the extensor carpi radialis longus muscle during 3 minutes of SHG at 15, at 30 and at 45% MVC. During SHG at 15% MVC, muscle blood flow increased by 25 fold from rest to exercise ($p<.05$), even though mean arterial pressure increased by only 12±4 mmHg. This large exercise-induced hyperemia was completely abolished during SHG at both 30% and at 45% MVC, despite large increases in mean arterial pressure of 29±3 and 56±5 mmHg, respectively. We conclude that, in contrast to what has been previously assumed, the reflex increases in blood pressure that accompany static handgrip are not able to increase blood flow to exercising forearm muscle at levels of exercise above 15% MVC. During static forearm exercise in humans, blood pressure does not appear to be an important determinant of muscle blood flow.

50.28

IS THE MUSCLE METABOREFLEX FUNCTIONALLY IMPORTANT IN THE CONTROL OF BLOOD FLOW TO ACTIVE SKELETAL MUSCLE? D.S. O'Leary and D.D. Sheriff. Department of Physiology, Wayne State University, Detroit, MI 48201 and Department of Physiology and Biophysics, University of Washington, Seattle, WA 98195.

Graded partial occlusion of terminal aortic blood flow (TAQ) was performed in 5 conscious, chronically instrumented dogs during mild (3.2 KPH, 0% grade) and moderately-heavy (6.4 KPH, 10% grade) treadmill exercise while monitoring systemic arterial pressure (SAP), hindlimb perfusion pressure (measured in the femoral artery [FAP]) and TAQ. Partial inflation of the vascular occluder increased hindlimb vascular resistance (calculated as SAP/TAQ which includes resistance due to occlusion and vascular responses in the hindlimb) and if no pressor response occured the initial level of TAQ (TAQi) should decrease in proportion to the increase in resistance. However, with a reflex increase in SAP, the observed TAQ (TAQo) increased above the values predicted (TAQp) by the increase in resistance. Metaboreflex closed loop gain (Gcl) was calculated as Gcl = - [TAQo - TAQp)/ (TAQi - TAQp)]. During mild exercise, initial levels of partial occlusion did not induce pressor responses, TAQo approximated TAQp and Gcl was not significantly different from 0. However, once beyond metaboreflex threshold, further occlusion induced pressor responses; TAQo increased above TAQp and Gcl averaged 0.51 ± 0.07. In contrast during moderately-heavy exercise, the initial levels of occlusion caused pressor responses. Once activated metaboreflex gain remained essentially constant with further occlusion and Gcl averaged 0.45 ± 0.04. Thus, with vascular occlusion during dynamic exercise the muscle metaboreflex is capable of restoring ~ 45 - 50 % of the deficit in blood flow to the active skeletal muscles. (Supported by NIH HL 45038 and HL 46314)

50.29

CAN INCREASING BLOOD FLOW TO ACTIVE MUSCLES BLUNT THE SYMPATHETIC ACTIVATION NORMALLY ASSOCIATED WITH HANDGRIPPING IN HUMANS?

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Eight subjects performed two 6 minute trials of rhythmic (30/min) handgripping at 50% of maximum. One trial served as a control, and during the other 50 mmHg of suction was applied around the forearm to augment muscle blood flow. The contractions were followed by two minutes of post-exercise ischemia. Mean arterial pressure (MAP), heart rate (HR), and muscle sympathetic nerve activity (MSNA, peroneal nerve) were measured continuously. In pilot studies the suction caused deep forearm vein O_2 saturation to rise from ~35 to 45%, indicating that blood flow to the active muscles had increased by ~20%. During the exercise MAP increased from 99±4 to 129±6 during control and from 99±4 to 126±6 with suction ($P<0.05$ vs control during the final minute of exercise). MSNA increased from 376±67 to 970±125 during the control trial and from 396±69 to 729±94 units with suction ($P<0.05$ vs control). During post-exercise ischemia MAP was 10 mmHg lower after the suction trial ($P<0.05$ vs control), and the differences in MSNA seen during exercise continued. The HR responses were similar in the two trials. These results indicate that forearm suction limited the activation of chemoreflexes from active muscles, but only minimally altered the arterial pressure responses during exercise.

50.30

RESPONSES OF GROUP III MUSCLE AFFERENTS TO DYNAMIC EXERCISE. J.G. Pickar*, J.M. Hill, M.P Kaufman, University of California, Div. of Cardiovascular Medicine, Davis, CA 95616

Group III muscle afferents in part mediate the reflex cardiopulmonary responses to exercise. "Exercise" is typically induced by electrical stimulation of the appropriate ventral root. This maneuver excites α-motoneurons in the reverse physiological order. We recorded the responses of Group III muscle afferents to locomotion induced by stimulation of the mesencephalic locomotor region (MLR) in decerebrate cats. The rhythmic walking induced by MLR stimulation represents a true form of dynamic exercise since α-motoneurons are recruited in a physiological order during slow walking. Single unit afferent activity was recorded in thin filaments teased from the L7 or S1 dorsal roots. Muscle tension generated by the contracting triceps surae muscles was recorded. Single unit afferent activity in response to rhythmic locomotion was recorded from 5 group III muscle afferents whose receptive fields were located in the triceps surae muscles. None of the group III afferents discharged at rest. Two group III muscle afferents (c.v.: 4.7 and 5.4 m/s) were responsive to passive muscle stretch (threshold 2.5kg), but during locomotion they were weakly stimulated by triceps surae contractions of only 0.05kg. On the other hand, three group III muscle afferents (c.v.: 11.3-13.0 m/s) were insensitive or weakly sensitive to passive stretch of the triceps surae, but during locomotion each responded to low levels of active muscle contraction (0.05-3.1 kg) with each unit discharging 1 to 6 times during a single step cycle. These data suggest that Group III muscle afferents can respond to the low active tension of slowly conducting motor units which are recruited first during physiological exercise. Supported by HL-30710.

50.31

NEURONS IN THE VENTROLATERAL MEDULLA RECEIVE INPUT FROM DESCENDING "CENTRAL COMMAND" AND FEEDBACK FROM CONTRACTING MUSCLES.. P.C. Nolan, J.A. Pawelczyk and T.G. Waldrop. Dept. of Physiology & Biophysics, Neuroscience Program and College of Medicine, Univ. of Illinois, Urbana, IL. 61820

Feedback from contracting muscles and descending central command are two neural mechanisms responsible for adjusting cardiorespiratory activity during exercise. Prior studies have focused on identifying supraspinal sites involved in exercise regulation; however, little is known about brain sites that integrate input from the various mechanisms active during exercise. The purpose of the present study was to determine if integration occurs in the ventrolateral medulla (VLM). The single unit responses of neurons in the ventrolateral medulla to contraction of hindlimb muscles (elicited by stimulation of the L7 and S1 ventral roots) and to activation of simulated central command (caudal hypothalamic stimulation) were examined in anesthetized cats. As previously reported, muscular contraction increased the discharge frequency of many VLM neurons; approximately fifty percent of the VLM neurons that responded to muscular contraction were also sensitive to hypothalamic stimulation. Moreover, computer analyses revealed that these neurons had a basal discharge frequency related to cardiovascular and/or respiratory rhythms. The neuronal response to hypothalamic stimulation was not due to muscular contraction since the responses persisted after muscular paralysis. These results demonstrate that individual VLM neurons receive input from contracting muscles and from the central command mechanism. Thus, integration of these neural mechanisms active during exercise may occur in the ventrolateral medulla (Supported by NIH 06296 & Illinois AHA).

50.32

CENTRAL COMMAND IS AIDED BY THE RVLM (ROSTRAL VENTROLATERAL MEDULLA) IN THE DOG. K.J. Dormer and S.R. Ashlock. Dept. Physiology, Univ. Oklahoma Health Sci. Ctr., Oklahoma City, OK 73190.

A subset of the catecholamine-containing cells in the RVLM have been implicated in vasomotor control. C1 area cells have monosynaptic input to the preganglionic sympathetic neurons of the spinal cord and receive descending inputs from the higher CNS. The role of RVLM in support of treadmill exercise was tested in dogs measuring heart rate (HR), cardiac output (CO), arterial (aortic) pressure (AP), internal thoracic (IT) and renal artery (RA) blood flows. Submaximal exercise tolerance testing was conducted on 15 dogs before and after incomplete, unilateral lesions were made with stereotaxic microinjection of kainic acid (100 mM, 100 nl) into the RVLM. Comparing grouped pre-lesion averaged results for 3 ETT's with the results post-lesion there was a significant decrease in resting and exercise total peripheral resistance and AP. CO, peak aortic blood flow and IT but not RA were reduced but not significantly. No behavioral, motor or cognitive changes were observed. Lesions were approximately 1 mm diameter in the rostral C1 cell column at the retrofacial area near the compact division of nucleus ambiguus. We conclude that RVLM may be universally involved in AP control during rest and exercise.

Author Index

The number to the left of the decimal designates the session. The abstract number follows the decimal. A zero indicates that participation was invited and an abstract was not required.

E

F

G

H

I