Skeletal Muscle Glycogen Depletion and Recovery During Four Consecutive Days of Prolonged Lift and Carry Exercise

Thomas B. Price[1]* and David M. Brady[2]

[1]Department of Health Sciences, Coordinator of Exercise and Fitness Program, School of Arts and Sciences, University of Bridgeport, 169 University Avenue, Bridgeport, CT 06604, USA

[2]Vice-Provost, Health Sciences Division Director, Human Nutrition Institute, Associate Professor of Clinical Sciences, University of Bridgeport, 126 Park Avenue #720, Bridgeport, CT 06604, USA

Keywords: Skeletal muscle; Glycogen; Exercise; C-13 NMR; Depletion; Recovery; Gender

Introduction

A signi cant number of occupations include li ing and carrying heavy objects as a part of the job description. Any job that involves moving supplies, perishables, or merchandise can include extended periods of li /carry work. When an employee performs this type of work day-in and day-out the risk of injury can rise as muscles gradually fatigue. Muscles, which rely on stored carbohydrates to provide fuel for these daily bouts of work, may gradually reduce their energy reserves over several consecutive days of work [1-3]. When a muscle with signi cantly reduced energy reserves is called upon to perform prolonged work, it is possible that the workload will need to be re-distributed to di erent muscles [4]. Adaptation of di erent movement patterns has been observed in women performing fatiguing repetitive exercise [4-8]. is adaptation can result in “less-than-optimal” bi91taw8nicalrforof d a musc0d

***Corresponding author:** Thomas B. Price, Associate Professor, School of Arts and Sciences, 169 University Avenue, Bridgeport, CT 06604, USA, Tel: 203-576-4197; Fax: 203-576-4262; E-mail: tprice@bridgeport.edu

Received May 27, 2015; **Accepted** June 18, 2015; **Published** June 25, 2015

Citation: Price TB, Brady DM (2015) Skeletal Muscle Glycogen Depletion and Recovery during Four Consecutive Days of Prolonged Lift and Carry Exercise. Occup Med Health Aff 3: 207. doi:10.4172/2329-6879.1000207

for 42-58% of all WRI's [15-17]. U.S. costs related to MSD injuries rose 2.7-fold ($81-$215 billion) over the 20-year period ending in 2005 [18].

ese injuries are a particular problem with monotonous jobs in which the worker has little control over how they must perform their work [15]. Jobs that demand intensive work under time and performance pressures with little task variability place workers at risk of upper extremity musculoskeletal disorders [19] as well as back injuries, the most common reason for work-related absences [18]. While the scienti c community generally agrees that job variability bene ts musculoskeletal health [20-22], current trends in task-automation and the increasing use of temporary labor during production and delivery peaks have led to reductions in task variability [23,24].

Skeletal muscle carbohydrate utilization and recovery has been studied during consecutive days of running [1-3], cycling [2,25], and swimming [26] exercise in both trained and untrained human subjects, as well as animals [27]. However to our knowledge, carbohydrate metabolism during consecutive days of repetitive li ing has never been studied. A study of trained and untrained runners working at 80% VO_{2max} has shown that glycogen utilization decreases over several consecutive days of exercise, while reliance on free fatty-acids increases [1]. Another study of untrained subjects performing three consecutive days of running and cycling exercise on separate occasions observed that glycogen recovery failed to return to initial resting levels by the third day of exercise [2]. In that study diet was controlled to 5 g carbohydrate/kg body mass per day, and the authors concluded that the reduced glycogen recovery was due to the moderate carbohydrate intake during the recovery periods [2]. In a third study, trained cyclists performed ve consecutive days of cycling 20 km/day at 80% VO_{2max} and had diet controlled to either 50% (LoCarb) or 100% (EqCarb) of their normal carbohydrate load [3]. Results of that study indicated that in both conditions (LoCarb and EqCarb) muscle glycogen failed to return to initial resting levels during the recovery periods; however, the depletion/insu cient recovery pattern was much more pronounced in the LoCarb condition [3]. A fourth study examined a number of other metabolic responses during three consecutive days of cycling at 60% VO_{2max}

Figure 1: Repetitive lifting exercise ergometer consisting of a roller apparatus of the type normally used for moving boxes in a warehouse (3.3 meters in length, 1.32 meters high at upper end and 0.13 meters at lower end). The box (12 inches × 12 inches × 16 inches) was constructed of high molecular weight plastic (1.5 inches thickness) with handles mounted at 45°angles. The box weight (45 pounds) was augmented by mounting circular weights (20 pounds) with a threaded nylite rod.

Magnetic resonance spectroscopy

Natural abundance ^{13}C-NMR spectroscopy was performed at 2.1 T on a Bruker Biospec spectrometer with a 100-cm-diameter magnet bore according to a previously described protocol [31]. During the measurements, subjects remained supine within the magnet with a surface coil radio-frequency (RF) probe resting directly over the muscle to ensure that the majority of the NMR signal was received from the muscle of interest (Vastus lateralis/intermedius or Biceps brachialis). A microsphere containing a ^{13}C-labeled formate was xed at the center of the RF coil for calibration of RF pulse widths. Subjects were positioned by an image-guided localization routine that employs a T_1-weighted gradient-echo image (repetition time=82 milliseconds, echo time=21 milliseconds). Subjects were positioned so the isocenter of the magnetic eld was approximately two centimeters into the muscle. By determining the 180°- ip angles at the center of the observation coil from the microsphere standard, RF pulse widths were set so the 90°-pulse was sent to the center of the muscle. is technique maximizes suppression of the lipid signal that arises from the subcutaneous fat layer and optimizes the signal from the muscle. e ^{1}H-decoupled ^{13}C RF pulse sequence was designed so that 5472 summed ^{13}C transients were obtained. e repetition time for ^{13}C acquisition was 87 ms, and ^{1}H continuous wave decoupling was truncated to 25milliseconds at the beginning of each ^{13}C acquisition to prevent excessive RF power deposition in the muscle. During the data acquisition period, RF power was pulsed through the surface coil at a frequency of 22.5 MHz (^{13}C resonance frequency). A 9-centimeter diameter circular ^{13}C surface coil RF probe was used for spectral acquisitions. Shimming, imaging, and ^{1}H decoupling at 89.5 MHz was performed with a 12 X 12-centimeter series butter y coil. Proton line widths are typically shimmed to 70 Hz. e total scan time for each spectrum was eight minutes. Pre- and post-exercise spectra were collected from the le Vastus lateralis and le Biceps brachialis.

Statistical analysis

NMR precision was calculated by pooled variance analysis [35,36]. Paired two-tailed *t*-tests were used for comparison of data within individual subjects. Between-group comparisons were performed using ANOVA with Bonferroni correction factor. Data are presented as mean ± SE and signi cance is calculated according to $^{*}p \leq 0.05$

Results

Subjects maintained a diet log over fourteen days prior to, and during the four-consecutive day li -and-carry exercise protocol. Subject dietary data are presented in Table 1. Caloric intake did not di er in either gender before versus during the four-day protocol, nor did it di er between genders. Subjects consumed a mixed-meal diet of roughly 50% carbohydrates, 30% fat, and 20% protein that did not change signi cantly during the four-day protocol. Carbohydrate consumption was in the range of 3-4 g/kg BM and did not change during the protocol.

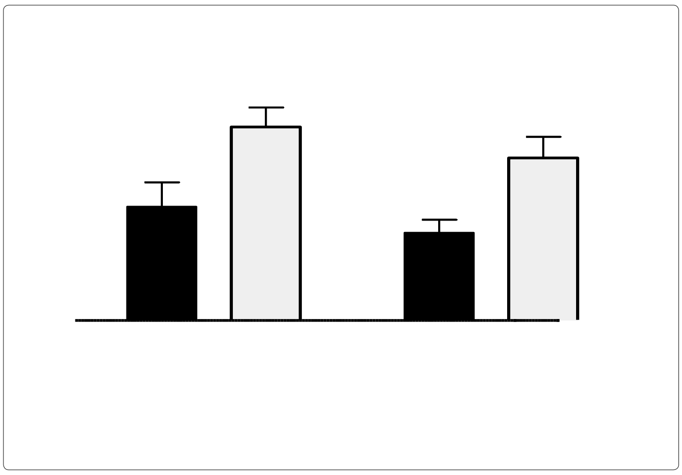
Muscle glycogen consumption did not di er on each consecutive day of exercise in either the male (M) or the female (F) subjects (Table 2). is pattern held true for both the quadriceps and the biceps muscles (20.4 ± 6.9 mM (M), 19.7 ± 3.9 mM (F) Quadriceps, 15.7 ± 4.8 mM (M), 17.0 ± 3.1 mM (F) Biceps) (Table 2). Muscle glycogen recovery between consecutive days exercise did not di er in either group, the pattern holding true for both muscles (24.4 ± 6.0 mM (M), 26.2 ± 7.6 mM (F) Quadriceps, 23.4 ± 4.8 mM (M), 19.8 ± 3.5 mM (F) Biceps) (Table 3). No signi cant di erences were seen between genders in either glycogen consumption during exercise or glycogen recovery between exercise bouts. Because no gender di erences were observed M and F groups were combined and analyzed as overall glycogen consumption and recovery (Figure 2). A pattern of glycogen over-compensation was observed in both quadriceps (Figure 2A) and biceps (Figure 2B) muscles.

rates determined from the two-point analysis. Using this calculation, the men worked their quadriceps at 17% MVC and their biceps at 15%

e male group was able to complete more of the required exercise protocol (twelve hours over four days) compared with the female group (90 ± 8% M, 55 ± 13% F p=0.0366) (Table 4). Two males and one female completed 100% of the protocol. Because the females only completed 6.6 ± 1.6 total hours versus 10.8 ± 0.9 total hours completed by the males, mean glycogen depletion rates over the entire protocol di ered between genders (Figure 3). In the male quadriceps overall glycogen depletion rates were 0.6X female rates (p=0.0475), and in the male biceps brachialis overall rates were 0.5X female rates (p=0.0270).

Discussion

is study demonstrates that, while women are not able to complete as much of a challenging non-normalized four day repetitive li ing and carrying task as men, their overall day-to-day depletion and recovery of muscle glycogen reserves in prime movers is not signi cantly di erent from their male counterparts. Because the women were able to continue to work only about 60% as long as the men and during this time utilized similar amounts of muscle glycogen, calculated glycogen depletion rates were greater in women than in men. is rate calculation, based on a two-point analysis, does not consider the possibility of a glycogen depletion pattern that levels o at some point during the exercise bout, a pattern that has been previously reported but would require multiple data points over the period of exercise [37]. Workloads for male and female quadriceps and biceps muscles may be estimated as % Maximum Voluntary Contraction (%MVC) using glycogen depletion



Suggestions for the monitoring of activity-induced perturbation in metabolic pathways of energy production in any subsequent investigation may include the use of organic acid testing through serial timed urine sample collection of subjects over the course of the study. Urinary markers of key metabolic intermediates in the production of ATP, as well as nutrients involved as enzyme cofactors in central energy pathways, can be seen in Figure 4. Interesting possible observations could include changes over time in pathway efficiency and possible evidence of increased requirements for specific nutrient enzyme cofactors to mitigate any inefficiencies in energy production induced by prolonged physical demand on the musculature. Possible strategies may emerge clinically to mitigate over-reliance on anaerobic pathways and the overproduction of the resultant acidic metabolites such as lactic acid. Such strategies might include recommended dietary manipulation or targeted supplementation for subjects placed into high-demand physical activities over prolonged time intervals and/or successive days.

It has long been thought that as energy reserves decline the body compensates by altering muscle activity patterns, thereby increasing the risk of injury. The unexpected result that these two muscles, primary movers in this exercise, super-compensate rather than under-compensate during consecutive days of exercise supports the idea that it is not a reduction in energy reserves that leads to an increase in the risk of work related injuries (WRI's). When this factor is removed as a possible source of injury, proper lifting and carrying form becomes more important. Subjects participating in this study were heavily monitored for proper lifting form throughout each exercise period, and encouraged to use correct form when deterioration of form was noted. This type of coaching does not exist in the workplace, and deterioration of form may progressively increase over the course of a workday. It should be noted that the exercise protocol employed in this study is 3 hours of work over a roughly 3.5 hour period, which represents about half of a standard work shift.

and 3 hrs following a 160 km sled run conducted on ve consecutive days [27]. To our knowledge, this is the only study aside from the current study that obtains post-exercise glycogen measurements on a series of consecutive days. In that study dogs were fed a controlled diet of 50% fat, 35% protein, and 15% carbohydrate and allowed to rest 7-8 hrs halfway through the run (80 km) and again at the end of the run (160 km) [27]. Biopsies were obtained 3 hrs a er run completion and before the dogs were allowed to eat the second meal [27]. e pre- and post-exercise glycogen values obtained in the McKenzie study are in agreement with values obtained in human data from this laboratory showing on average 54-64% of glycogen recovered at 3 hrs a er cessation of exercise with no food intake following exercise and prior to glycogen measurement [27,31,40,41]. With the exception that this study observes day-to-day super-compensation in exercised muscles, the current results are largely in agreement with previous studies

Recovery of muscle glycogen concentrations in sled dogs during prolonged exercise. Med Sci Sports Exerc 37: 1307-1312.

28. Hultman E (1967) Muscle glycogen in man determined in needle biopsy specimens: method and normal values. Scand J Clin Lab Invest 19: 209-217.

29. Taylor R, Price TB, Rothman DL, Shulman RG, Shulman GI (1992) Validation of 13C NMR measurement of human skeletal muscle glycogen by direct biochemical assay of needle biopsy samples. Magn Reson Med 27: 13-20.

30. Price TB, Laurent D, Petersen KF, Rothman DL, Shulman GI (2000) Glycogen loading alters muscle glycogen resynthesis after exercise. J Appl Physiol 88: 698-704.

31. PriceTB, Perseghin G, Duleba A, Chen W, Chase J, et al. (1996) NMR studies