Occupational Medicine & Health Affairs

Price and Brady, Occup Med Health Aff 2014, 3:3
http://dx.doi.org/10.4172/2329-6879.1000207

Research Article Open Access

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*

Abstract

A substantial portion of the nation's working population has jobs that involve lifting and carrying heavy objects. Muscles metabolize carbohydrate stores to accomplish such work. Little is known about how muscles replenish carbohydrates from day to day during the workweek.

Objective: This study documents muscle glycogen depletion and recovery in two muscles routinely used in extended lifting and carrying exercise, and determines the extent to which four days of such exercise affects muscle glycogen levels.

Methods: Ten subjects (5 M, 5 F) were studied; age 25 ± 4 y M, 22 ± 2 y F, weight 92 ± 8 kg* M, 62 ± 5 kg F, and height 185 ± 3 cm* M, 170 ± 2 cm F. Subjects recorded their diet before and during the protocol. On four consecutive days subjects were asked to squat to floor level and lift a 30 kg box, carry it 3 m, and place it on a shelf 132 cm high. This was repeated 3X/min over a three hour period (540 lifts) or until the subject could no longer continue. Subjects were allowed five minutes rest every 30 min. Exercise was performed at the same time of day, allowing nineteen hours of recovery between bouts. The protocol was not normalized for subject gender or size. Natural abundance C-13 NMR was performed on the left quadriceps and left biceps brachialis immediately before and after each exercise bout. Ability to complete the prescribed protocol, dietary intake before and during the protocol, and muscle glycogen levels before and after exercise were recorded and compared.

Results: Subjects differed significantly by gender in their ability to complete the four-day protocol (12 hours total protocol: 10.8 ± 0.9 hr M, 6.4 ± 1.6 hr F, p=0.0366). Dietary intake did not differ during the four-day protocol versus prior to the study (2109 ± 256 kcal/da M prior, 2107 ± 87 kcal/da M during, 1657 ± 136 kcal/da F prior, 1755 ± 331 kcal/da F during). In the biceps brachialis (both genders combined) pre-exercise glycogen levels rose significantly over the four-day protocol (vs. day one) [62.3 ± 3.6 mmol/L D1, 68.5 ± 4.6 mmol/L (p=0.0437) D2, 75.1 ± 4.9 mmol/L (p=0.0019) D3, 81.9 ± 5.4 mmol/L (p=0.0003) D4, paired analysis vs. D1]. In the quadriceps a similar pattern was seen [92.2 ± 9.0 mmol/L D1, 101.3 ± 8.9 mmol/L (p=0.0107) D2, 110.3 ± 10.2 mmol/L (p=0.0089) D3, 115.9 ± 9.8 mmol/L (p=0.0003) D4 paired analysis vs. D1].

Conclusions: We conclude that male and female muscle glycogen is similarly supercompensated between each day of four consecutive days of prolonged exercise, in the absence of increased dietary intake.

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

Introduction

A significant number of occupations include lifting 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 lift/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 significantly reduced energy reserves is called upon to perform prolonged work, it is possible that the workload will need to be re-distributed to different muscles [4]. Adaptation of different movement patterns has been observed in women performing fatiguing repetitive exercise [4-8]. This adaptation can result in "less-than-optimal" biomechanical form, which can lead to occupational injuries [8]. The upper body isometric mean lifting strength (MLS) of women is about 60% of men [9]. Male versus female lifting performance has been well studied employing dynamic lifting of a maximally loaded box from floor level to shoulder height [10,11]. Men also have greater muscular endurance than women when repetitively lifting an absolute load, suggesting that women will fatigue faster than men under identical lifting conditions [9,11,12].Therefore, women who work in occupations that require prolonged repetitive lifting may be at even greater risk of musculoskeletal injury, when working alongside men, under daily time constraints when a job needs to be done [8,13,14]. Little is known about how muscles replenish stored carbohydrates from day-to-day during a work week that consists of consecutive bouts of lifting-and-carrying heavy objects.

Musculoskeletal disorders (MSD's) have been shown to be the largest single contributor to work related illnesses (WRI's), accounting

***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]. These 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 scientific community generally agrees that job variability benefits 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 lifting 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 five 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/insufficient 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} followed by three days of recovery [25]. This study observed a 50% drop in intramuscular creatine phosphate on all days of exercise that recovered completely at 24 hours [25]. Other intramuscular metabolites (glucose, glucose-6-phosphate, and lactate) rose significantly during exercise and recovered completely within 24 hours [28-32]. The glucose transport protein (GLUT4) was significantly elevated over consecutive days of exercise and elevated further (1.4X) over three days of recovery [25]. Finally, muscle glycogen was significantly depleted during each consecutive day of exercise returning to 95% of initial levels at 24 hours of recovery, supercompensating to 1.2X at 48 hours of recovery [25].

The purpose of this study was to examine muscle glycogen depletion and recovery in two of the muscles that are routinely used in prolonged lifting and carrying exercise, and to determine the extent to which four consecutive days of extended exercise affects muscle glycogen levels. Study results were compared in male and female populations. All of the previously cited studies obtained muscle glycogen data utilizing a muscle needle-biopsy technique to obtain study samples [1-3,25-28]. This study utilizes natural abundance ^{13}C magnetic resonance spectroscopy (MRS) to obtain muscle glycogen data [29-31]. The aim of this study was to examine the effect of four consecutive days of a prolonged, non-normalized, repetitive lift and carry task upon carbohydrate depletion and recovery in exercised male and female muscles.

Specifically, the study was intended to assess [1] any trends in glycogen recovery from day-to-day over the course of the protocol, and [2] potential gender differences in any trends observed. Experiments were designed to test the following hypothesis: Four consecutive days' performance of the same prolonged repetitive lifting task causes an overall downward trend in carbohydrate stores. This downward trend may be the result of incomplete recovery from each previous day's exercise. The trend may also be more pronounced in women than in men.

Methods

Subjects

Ten subjects (5M, 5F) were studied. Males (25 ± 3 yrs, 92 ± 8 kg, 185 ± 3 cm) and females (21 ± 2 yrs, 62 ± 5 kg*, 170 ± 3 cm*, $p \leq 0.02$ versus males) were age, but not weight and height matched. All subjects were non-smokers, five were occasional drinkers (<5/wk). All subjects were matched for fitness, with no M vs. F differences between regular exercise regimens (1.6 ± 0.3 hr/day). When administered the Army Physical Fitness Test (Form DA 705), M and F scores were not significantly different. Composite percentiles were: 96 ± 3 percentile, sit-ups; 96 ± 2 percentile, push-ups; 100 ± 0 percentile, two-mile run. Women were studied in the mid-luteal phase of menstrual cycle [32-34].

Subject diet

Subjects recorded their diet for 14 days prior to the protocol and during the four-day protocol. Dietary analysis was performed using Nutritionist Pro software (Redmond, WA). Male and female diets were compared for macronutrient composition.

Exercise protocol

Subjects were asked to squat and lift a weighted box (30 kg) from six inches above floor level, walk 3 meters carrying the box and place it on the upper end of an exercise ergometer at a height of 1.3 meters (Figure 1). Upon placement, the box travelled back to floor level and was lifted again. The exercise protocol, consisting of three hours of squat/lifts per day at three lifts per minute (one lift every twenty seconds) with five minutes rest every thirty minutes (540 lifts/day), was the same for both female and male subjects. This protocol was performed on four consecutive days. Total exercise time (four days) was twelve hours (2160 total lifts). The exercise protocol was performed at the same time each day (8:30 AM arrival, 10:00 AM begin exercise protocol) with approximately nineteen hours separating the end of each exercise bout from the start of the next bout. The exercise protocol was not normalized for subject size or gender with both genders being asked to perform identical tasks. On the day of the study, subjects were allowed to eat immediately upon waking (liquid meal) and no further meals were allowed until the exercise session was completed. Each day, baseline MRS measurements were made in the left quadriceps muscle group (Vastus lateralis) and the left upper arm (Biceps brachialis) prior exercise. On each consecutive day of exercise MRS data were obtained from these two sites following completion of the protocol. On each day the exercise protocol was continued until subjects either completed the task or could no longer continue to exercise. During the fourteen day preparation each subject spent approximately thirty minutes familiarizing themselves with the exercise ergometer, and learning proper squat/lift technique.

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 fixed 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 field was approximately two centimeter into the muscle. By determining the 180°-flip 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. This technique maximizes suppression of the lipid signal that arises from the subcutaneous fat layer and optimizes the signal from the muscle. The ^{1}H-decoupled ^{13}C RF pulse sequence was designed so that 5472 summed ^{13}C transients were obtained. The 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 butterfly coil. Proton line widths are typically shimmed to 70 Hz. The total scan time for each spectrum was eight minutes. Pre- and post-exercise spectra were collected from the left Vastus lateralis and left 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 significance 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 lift-and-carry exercise protocol. Subject dietary data are presented in Table 1. Caloric intake did not differ in either gender before versus during the four-day protocol, nor did it differ between genders. Subjects consumed a mixed-meal diet of roughly 50% carbohydrates, 30% fat, and 20% protein that did not change significantly 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 differ on each consecutive day of exercise in either the male (M) or the female (F) subjects (Table 2). This 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 differ 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 significant differences were seen between genders in either glycogen consumption during exercise or glycogen recovery between exercise bouts. Because no gender differences were observed M and F groups were combined and analyzed as overall glycogen consumption and recovery (Figure 2). A pattern of glycogen overcompensation was observed in both quadriceps (Figure 2A) and biceps (Figure 2B) muscles.

	Before		During	
	Male	Female	Male	Female
Diet Intake [kcal/day]	2109 ± 256	1657 ± 136	2107 ± 87	1755 ± 331
Carbohydrate %	53	46	51	53
Carbohydrate [g/day]	279 ± 36	191 ± 23	236 ± 33	233 ± 53
Lipid %	28	33	30	30
Lipid [g/day]	66 ± 7	61 ± 4	70 ± 6	59 ± 11
Protein %	19	20	19	17
Protein [g/day]	100 ± 15	83 ± 6	100 ± 7	75 ± 10

Table 1: Dietary data for male and female subjects in the 14 days prior to the consecutive days exercise protocol and during the four day protocol. Percentages of carbohydrates, lipids and proteins are representative of a standard mixed-meal diet. No significant differences were noted in any of the variables between either males versus females or before versus during the protocol. Values given as mean ± SE.

	Male		Female	
	Quadriceps	Biceps	Quadriceps	Biceps
Day 1 [mM]	20.4±5.5	12.5±4.0	11.6±3.8	11.6±3.8
Day 2 [mM]	15.3±8.2	19.6±3.9	18.2±4.4	15.8±1.7
Day 3 [mM]	20.8±5.2	13.9±5.1	20.0±4.3	13.2±2.2
Day 4 [mM]	28.0±8.5	16.9±6.1	16.9±6.1	23.3±5.7
Average Depln [mM]	20.4±6.9	15.7±4.8	19.7±3.9	17.0±3.1

Table 2: Daily glycogen depletion [mM] shown during four consecutive days of lift-and-carry exercise in male and female quadriceps and biceps muscles. Bottom row is average glycogen depletion over the four day period. Data are presented as mean ± SE.

	Male		Female	
	Quadriceps	Biceps	Quadriceps	Biceps
Day 1-2 [mM]	23.1 ± 5.9	22.0 ± 2.6	25.2 ± 3.2	18.5 ± 2.4
Day 2-3 [mM]	24.3 ± 6.6	25.8 ± 2.9	27.2 ± 9.7	22.7 ± 1.8
Day 3-4 [mM]	25.9 ± 6.6	22.4 ± 6.4	26.3 ± 6.9	18.3 ± 4.3
Average Rec [mM]	24.4 ± 6.0	23.4 ± 4.8	26.2 ± 7.6	19.8 ± 3.5

Table 3: Day-to-day glycogen recovery [mM] shown during four consecutive days of lift-and-carry exercise in male and female quadriceps and biceps muscles. Bottom row is average over the four day period. Data are presented as mean ± SE.

The 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 differed 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

This study demonstrates that, while women are not able to complete as much of a challenging non-normalized four day repetitive lifting and carrying task as men, their overall day-to-day depletion and recovery of muscle glycogen reserves in prime movers is not significantly different 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. This rate calculation, based on a two-point analysis, does not consider the possibility of a glycogen depletion pattern that levels off 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 rates determined from the two-point analysis. Using this calculation, the men worked their quadriceps at 17% MVC and their biceps at 15% MVC, while the women worked quadriceps at 24% MVC and biceps at 21% MVC. When the possibility that glycogen depletion proceeded for a portion of the work period and then levelled off is considered, workloads are not as great. Under this condition both men and women worked quadriceps and biceps at 11%-14% of MVC. This calculation is based upon the net amount of glycogen depleted, and would suggest that during the three-hour exercise protocol either one or both muscles reduced or stopped glycogen depletion and converted to mostly fat catabolism [37]. Both of these workload calculations are speculative and therefore are discussed here rather than in the results; however, it is reasonable to speculate that:(1) workloads in these two muscles are fairly low in both men and women, (2) the two-point analysis probably overestimates workloads and the real workload is somewhere in-between the numbers calculated by these two methods, and (3) the body distributes the workload between many muscles during this particular lift/carry exercise so that no individual muscle is heavily challenged. Glycogen recovery between bouts of exercise was similar in both genders, exhibiting a pattern of super-compensation in both muscles by day four. When male and female data sets were combined, day-to-day super-compensation was observed each day relative to day one in both the biceps and the quadriceps. This result was unexpected and not in agreement with previous studies [1-3,25-27]; however, to our knowledge this is the first study of muscle glycogen depletion and recovery during consecutive days of lift and carry exercise. Both genders maintained a consistent mixed-meal diet that did not change during the four-day protocol, indicating that a change in diet did not drive the observed glycogen super-compensation. When taken together, the data from this study suggest that depletion of carbohydrate reserves may not be a significant factor in consecutive days of this type of heavy work.

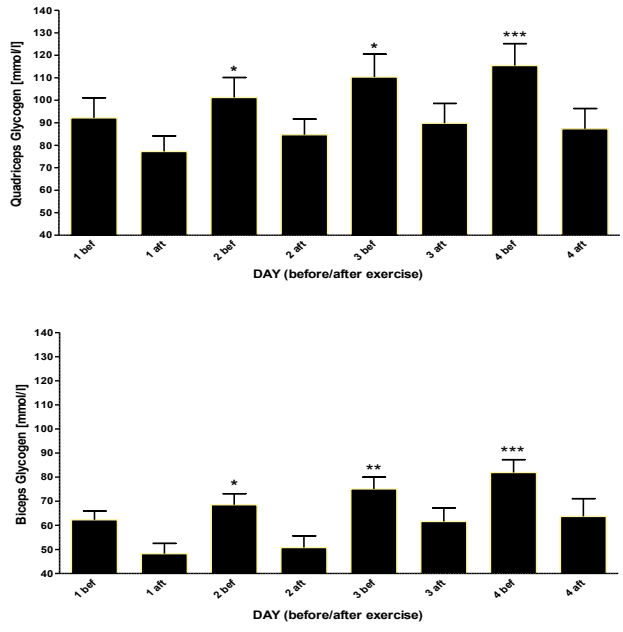

Figure 2: Muscle glycogen concentrations in quadriceps (A) and biceps (B) before and after lifting protocol on four-consecutive days. Data are given as mean±SE (*p ≤ 0.05, **p ≤ 0.005, ***p ≤ 0.0005 vs. resting glycogen before day one, paired analysis).

	Hours completed	% of protocol completed
Male	10.8 ± 0.9 hr*	90 ± 8%*
Female	6.4 ± 1.6 hr	53 ± 13%

Table 4: Ability to complete the entire four day protocol (12 total hrs) (*p=0.0366 vs. F). Data given as mean ± SE.

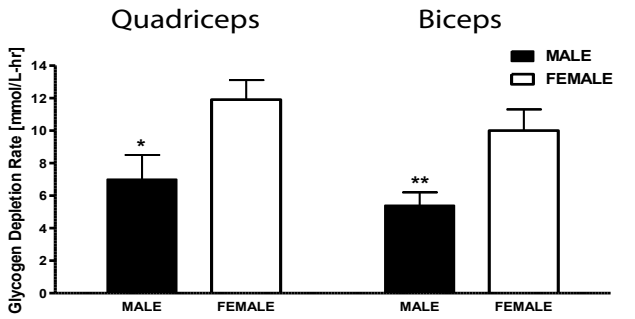

Figure 3: Mean glycogen depletion rates calculated (two-point analysis) over the four day protocol. Male glycogen depletion rates were significantly lower in both quadriceps and biceps muscle groups (*p=0.0475 quadriceps, **p=0.0270 biceps, unpaired analysis).

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.

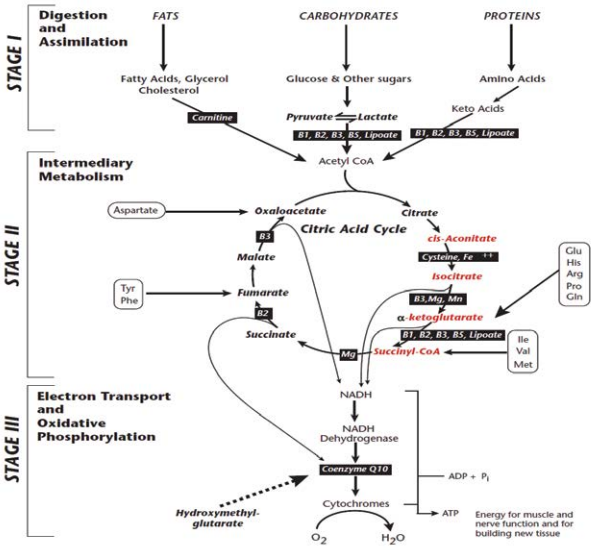

Figure 4: Urinary markers of nutrients involved in central energy pathways. From: Bralley JA, Lord RS (Editors): ***Laboratory Evaluations for Integrative and Functional Medicine*** (2nd Ed.). Brady D: Chapter on Gastrointestinal Function. 2008. Metametrix Inst. Duluth, GA.

The use of ergonomically-based functional screening tests has been proposed as a potential method of assessing new employees to reduce WRI's [37-39]. In order to develop such a screening program the employer would need to develop a set of tests that combines important tasks that would be expected on the job (work samples) with standardized physical ability tests [37,38]. An early study of steel workers combined work samples such as carrying 50 lb bags and jackhammers with physical ability tests combining strength (leg-lifts, push-ups, pull-ups, etc.) with balance and flexibility tests [39]. The amount of weight used in that study was similar to the amount of weight used in the current study. Another study compared screened employees with un-screened employees moving pallets and loading cases weighing up to 60 lbs in a food distributor at a rate of 125-150 lifts per hour, loading soft drink cases weighing up to 55 lbs (soft drink distributor) and unloading cases weighing up to 47 lbs at a retail distributor [38]. Energy expenditure, measured as oxygen consumption, in all work settings was around 50 ml/kg-min (49.5-53.3 ml/kg-min) [38]. Again in this study, both the weight and lifting rate were similar to those employed in the current study [38]. Both studies [38,39] demonstrated 47% lower workmen's compensation injuries and 21% greater job retention in screened employees as compared with un-screened employees.

In this study glycogen concentrations are measured in the quadriceps (v. lateralis, r. femoris) and biceps brachii immediately before and nineteen hours after exercise. The percent of measured glycogen following recovery vs. resting glycogen is in line with values seen following three consecutive days cycling exercise [25]. However in that study 24 hr recovery was slightly under-compensated and a small amount of super-compensation was seen only after 48 hrs recovery [25]. This difference may have resulted from the type of exercise employed the current study. However, it is more likely that the greater amount of glycogen depleted in the earlier study (>40% vs. 18-26% in the current study) played a more significant role [25]. In a biopsy study of sled dogs by McKenzie and colleagues, muscle glycogen was measured before

and 3 hrs following a 160 km sled run conducted on five 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 after run completion and before the dogs were allowed to eat the second meal [27]. The 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 after 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 [25,27,31,41]. This suggests that: (1) a difference in the type of exercise and/or the amount of glycogen depletion may play a role in glycogen recovery on consecutive days of exercise, (2) the distribution of workload amongst a number of different muscles minimizes glycogen depletion in this type of lift/carry exercise, and (3) depletion of muscle carbohydrate reserves may not be a major factor in injury risk during consecutive days of repetitive lift/carry exercise. Results from this study are also consistent with male vs. female upper body data that notes male/female differences in skeletal muscle mass as the primary contributor to strength differences [42]. In that study, female strength measurements averaged over a number of different movements was 61.2% of male strength [42]. When those measurements were normalized for skeletal muscle mass, female strength was 97% of male strength [42,43]. In this study, female ability to complete the exercise protocol was only 60% of males, suggesting that upper body strength may have played a role in the current results.

In summary, although women completed significantly less work than men, glycogen was progressively super-compensated in both genders (both muscles studied) throughout the four-day protocol. Dietary intake was not a factor in glycogen super-compensation. While overall glycogen depletion rates were greater in women than in men, total glycogen depletion and recovery was not significantly different between genders. We conclude that: (1) in both men and women glycogen is progressively super-compensated over four consecutive days of prolonged lift and carry exercise in two muscles that are primary movers, (2) owing to their smaller size, women work harder and accomplish less total work than men during the same (non-normalized) protocol, and (3) depletion of carbohydrate reserves is not a significant risk factor for work related injuries in prolonged repetitive lifting and carrying tasks.

Acknowledgements

This research was funded by the U.S. Army: Contract DAMD17-96-C-6097 and conducted at the Yale University School of Medicine, Department of Diagnostic Radiology.

References

1. Costill DL, Bowers R, Branam G, Sparks K (1971) Muscle glycogen utilization during prolonged exercise on successive days. J Appl Physiol 31: 834-838.
2. Pascoe DD, Costill DL, Robergs RA, Davis JA, Fink WJ, et al. (1990) Effects of exercise mode on muscle glycogen restorage during repeated days of exercise. Med Sci Sports Exerc 22: 593-598.
3. Kirwan JP, Costill DL, Mitchell JB, Houmard JA, Flynn MG, et al. (1988) Carbohydrate balance in competitive runners during successive days of intense training. J Appl Physiol (1985) 65: 2601-2606.
4. Selen LP, Beek PJ, van Dieën JH (2007) Fatigue-induced changes of impedance and performance in target tracking. Exp Brain Res 181: 99-108.
5. Qin J, Lin JH, Faber GS, Buchholz B, Xu X (2014) Upper extremity kinematic and kinetic adaptations during a fatiguing repetitive task. J Electromyogr Kinesiol 24: 404-411.
6. Hunter SK, Critchlow A, Shin IS, Enoka RM (2004) Fatigability of the elbow flexor muscles for a sustained submaximal contraction is similar in man and women matched for strength. J Appl Physiol 96: 195-202.
7. Hunter SK, Critchlow A, Shin IS, Enoka RM (2004) Men are more fatigable than strength-matched women when performing intermittent submaximal contractions. J Appl Physiol (1985) 96: 2125-2132.
8. Ge HY, Arendt-Nielsen L, Farina D, Madeleine P (2005) Gender-specific differences in electromyographic changes and perceived pain induced by experimental muscle pain during sustained contractions of the upper trapezius muscle. Muscle Nerve 32: 726-733.
9. Sharp MA (1994) Physical fitness and occupational performance of women in the u.s. Army. Work 4: 80-92.
10. Kroemer KH (1983) An isoinertial technique to assess individual lifting capability. Hum Factors 25: 493-506.
11. Beckett MB, Hodgdon JA (1987) Lifting and carrying capacities relative to physical fitness measures. Report No. 87-26, Naval Health Research Center, San Diego, CA.
12. Sharp DS, Wright JE, Vogel JA (1980) Screening for physical capacity in the US Army: An analysis of measures predictive of strength and stamina. Technical Report T8/80, US Army Research Institute of Environmental Medicine, Natick, MA.
13. Madeleine P, Mathiassen SE, Arendt-Nielsen L (2008) Changes in the degree of motor variability associated with experimental and chronic neck-shoulder pain during a standardised repetitive arm movement. Exp Brain Res 185: 689-698.
14. Latash ML, Anson JG (1996) What are normal movements in atypical populations? Behav and Brain Sci 19: 55-68.
15. Deeney C, O'Sullivan L (2009) Work related psychosocial risks and musculoskeletal disorders: potential risk factors, causation and evaluation methods. Work 34: 239-248.
16. Jones JR, Huxtable CS, Hodgson JT, Price MJ (2005) Self-reported work-related illness in 2003/2004: Results from the Labour Force Survey. Health and Safety Executive.
17. Jones JR, Huxtable CS, Hodgson JT (2008) Self-reported work-related illness in 2006/2007: Results from the Labour Force Survey. Health and Safety Executive.
18. Small Firms Association Ireland, Absenteeism Report (2008), Confederation House, 84-86 Lower Baggot Street, Dublin 2, Ireland.
19. NIOSH (1997) Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders for the neck, upper extremity and low back. BP Bruce, Ed. NIOSH, US Department of Health.
20. Mathiassen SE (2006) Diversity and variation in biomechanical exposure: what is it, and why would we like to know? Appl Ergon 37: 419-427.
21. Kilbom A (1994) Repetitive work of the upper extremity: part II-the scientific basis (knowledge base) for the guide. Int J Ind Ergon 14: 59-86.
22. Bongers PM (2001) The cost of shoulder pain at work. BMJ 322: 64-65.
23. Docherty P, Forslin J, Shani AB (2002) Creating sustainable work systems: Emerging perspectives and practice. Taylor & Francis, London.
24. Neumann WP, Kihlberg S, Medbo P, Mathiassen SE, Winkel J (2002) A case study evaluating the ergonomic and productivity impacts of partial automation strategies in the electronics industry. Int J Prod Res 40: 4059-4075.
25. Green HJ, Bombardier E, Duhamel TA, Stewart RD, Tupling AR, et al. (2008) Metabolic, enzymatic, and transporter responses in human muscles during three consecutive days of exercise and recovery. Am J Physiol: Regul Integr Comp Physiol 295: R1238-R1250.
26. Kirwan JP, Costill DL, Flynn MG, Mitchell JB, Fink WJ, et al. (1988) Physiological responses to successive days of intense training in competitive swimmers. Med Sci Sports Exerc 20: 255-259.
27. McKenzie E, Holbrook T, Williamson K, Royer C, Valberg S, et al. (2005)

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 of muscle glycogen synthesis in insulin resistant offspring of parents with non-insulin dependent diabetes mellitus immediately following glycogen depleting exercise. Proc Nat Acad Sci 93: 5329-5334.

32. Eston RG (1984) The regular menstrual cycle and athletic performance. Sports Med 1: 431-445.

33. Lebrun CM, McKenzie DC, Prior JC, Taunton JE (1995) Effects of menstrual cycle phase on athletic performance. Med Sci Sports Exerc 27: 437-444.

34. Reilly T (2000) The menstrual cycle and human performance: An overview. Biol Rhythm Rsch 31: 29-40.

35. Harris RC, Hultman E, Nordjesco L-O (1974) Glycogen, glycolytic intermediates and high-energy phosphates determined in biopsy samples of musculus quadriceps femoris of man at rest: methods and variance of values. Scand J Clin Lab Invest 33: 109-120.

36. Price TB, Rothman DL, Avison MJ, Buonamico P, Shulman RG (1991) 13C-NMR measurements of muscle glycogen during low-intensity exercise. J Appl Physiol (1985) 70: 1836-1844.

37. Anderson C, Briggs J (2008) A study of the effectiveness of ergonomically-based functional screening tests and their relationship to reducing worker compensation injuries. Work 31: 27-37.

38. Reilly RR, Zedeck S, Tenopyr ML (1979) Validity and fairness of physical ability tests for predicting performance in craft jobs. J Appl Physiol 64: 262-274.

39. Arnold JD, Rauschenberger JM, Soubel WG, Guion RM (1982) Validation and utility of a strength test for selecting steel workers. J Appl Physiol 67: 588-604.

40. Cady LD, Bischoff DP, O'Connell ER, Thomas PC, Allan JH (1979) Strength and fitness and subsequent back injuries in firefighters. J Occup Med 21: 269-272.

41. Berardi JM, Price TB, Noreen EE, Lemon PW (2006) Postexercise muscle glycogen recovery enhanced with a carbohydrate-protein supplement. Med Sci Sports Exerc 38: 1106-1113.

42. Alizadehkhaiyat O, Hawkes DH, Kemp GJ, Howard A, Frostick SP (2014) Muscle strength and its relationship with skeletal muscle mass indices as determined by segmental bio-impedance analysis. Eur J Appl Physiol 114: 177-185.

43. Bralley JA, Lord RS, Laboratory Evaluations for Integrative and Functional Medicine (2ndend) (2008). Brady D: Chapter on Gastrointestinal Function. Metametrix Inst. Duluth, GA.

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