QUANTITATIVE AND QUALITATIVE RECOVERY IN TRAINED FEMALES AFTER AN EXHAUSTIVE RESISTANCE TRAINING PROTOCOL, AND WITH A POST-EXERCISE CARBOHYDRATE-PROTEIN BEVERAGE

by

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A DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Kinesiology
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2010

ABSTRACT

In a series of three investigations, recovery was investigated in females following resistance exercise over varying recovery periods. Additionally, recovery when using a post-exercise carbohydrate (CHO-ONLY) or carbohydrate-protein (CHO-PRO) beverage was examined. Ten resistance trained females (21.1± 1.4 years of age) performed a baseline trial of three sets of eight exercises at their ten repetition maximum (10-RM). Later they completed four counterbalanced trials following 24, 48, 72, or 96 hours of recovery. No significant change ($p > 0.05$) occurred in group mean repetitions or ratings of perceived exertion (RPE) for any recovery period. Individual results showed 10% of participants recovered after 24 h, 80% following 48 h, and 70% at 72 h and 96 h of recovery. Soreness ratings were higher ($p < 0.05$) than baseline at all time points, diminished over time, and at 48 h was correlated to the group mean for repetitions ($r = -0.77$, $p = 0.01$). Participants performed the same exercise protocol, consumed either a CHO-PRO or CHO-ONLY beverage and attempted to replicate their performance 24 h later. Group mean repetitions, soreness, and RPE were similar ($p > 0.05$) with both beverages. With CHO-ONLY, 56% of participants recovered in 24 h versus 33% with CHO-PRO (versus 10% in first study). These findings suggest post-exercise consumption of a CHO-PRO or CHO-ONLY beverage may be advantageous for some exercisers. Lastly, the agreement between perceived recovery status (PRS) scores and actual recovery was measured following rest periods of varying length after resistance training. The PRS demonstrated high specificity for recovery for change in group mean repetitions (100%), total repetitions (95%) performed, and high

sensitivity (100%) for fatigue when participants indicated a score <five. In summary, trained females were recovered within 24 h following resistance training, despite considerable inter-subject variability and significant soreness. CHO-PRO and CHO-ONLY produced no change in the group mean for repetitions performed ($p > 0.05$), 24 h after weight lifting. However, supplementation with these beverages may be useful for those responsive to this type of nutritional intervention. Finally, the PRS scale may help identify individuals who have reached recovery before beginning a subsequent exercise session.

ACKNOWELDGEMENTS

I would like to express my most heartfelt appreciation to my committee members; Dr. Phil Bishop, Dr. Mark Richardson, Dr. Jonathan Wingo, Dr. James Leeper, and Dr. Jeanine Lawrence. Each of these committee members has shown exceptional generosity with their time, their guidance, and their encouragement throughout this process. Each individual has been selfless in their approach and have never turned me away. I want to especially thank Phil Bishop for his patience and dedication to helping me improve as a researcher and scientist, as well as, a person. I also want to express special gratitude to Mark Richardson who helped me start this endeavor and provided with great advice throughout. To both of these men I am indebted and hope to emulate their example.

I would like to thank Charlie Katica, Jean Ann Hargreaves, Greg Ryan, and Stacy Bishop, who volunteered their time and energy amidst their increasingly busy schedules. Their selfless attitudes and energy were extraordinary and encouraging throughout this process.

To my best friend Tiffany, the most loving person I have ever come in contact with; her presence in my life is the truest blessing I have ever known. To my family for their devotion and the pride they continually express, especially my parents who instilled in me the concept that work precedes success. To my brothers, for giving me my first opportunities to teach. They were exceptional students and became my greatest friends. Most importantly I want to thank God for the life I've been blessed with. He has always given me the strength to overcome the trials I've faced and the humility to accept the blessings I've received. He is my creator, my savior, and my greatest hope is to live a life that is an example of His love.

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INTRODUCTION

Resistance training has been shown to be an effective way to increase strength, promote muscle hypertrophy, and increase fat-free mass while reducing body composition. Therefore weight training has become an integral part of the conditioning program of both young and older exercisers of both genders. However, for adaptation to occur, the training stimulus must be of a magnitude to create a temporary disruption of the muscle's contractile machinery. This process of overloading the active muscles, followed by their temporary breakdown, in part, stimulates a subsequent increase in protein synthesis. This rise in protein synthesis, in the presence of adequate nutritional intake and rest, begins the repair process.

Until recently, resistance training investigations have focused primarily on the exercise stimulus in regards to the optimal intensity, duration, and frequency of training to maximize gains versus the time course for a full recovery. Although it is important to understand the physiologic stimulus required to produce the desired outcome from training, without a clear understanding of the recovery required to restore homeostasis, a person can become over-trained or injured. Additionally, strength training research has disproportionately studied males rather than females. Thus, little is known regarding the recovery capabilities of women engaging in regular resistance training.

Therefore, the aim of the current investigations was to evaluate the recovery in resistance trained, college-aged females following an intense bout of resistance training. Additionally, it has been demonstrated that muscle protein breakdown can exceed the rate of protein synthesis in the absence of adequate nutrition following resistance exercise. To that end, the efficacy of a post-exercise carbohydrate-protein (CHO-PRO) and carbohydrate-only (CHO-ONLY) beverage to enhance resistance training performance on consecutive days was also tested. Lastly, it may prove beneficial to provide exercisers with an easy-to-use and accurate assessment tool to evaluate their individual recovery needs as a part of the design of a weight training program. A perceived recovery status (PRS) scale that was originally created to evaluate recovery following repeated sprint intervals, was tested in the current investigations. The aim was to evaluate its validity for identifying the role of perceived recovery status relative to changes in weight lifting performance following variable recovery periods.

It was hypothesized, that women would be able to replicate their baseline performance of an exhaustive resistance training protocol following 24 h of recovery. Additionally, it was hypothesized that consumption of a CHO-PRO beverage post-exercise would reduce soreness while increasing mean repetition performance better than CHO-ONLY, in a repeated bout of exercise 24 hours after the original training session. Lastly, it was presumed that the PRS scale would be able to accurately identify both recovered and fatigued participants based on changes in mean repetitions performed following 24, 48, 72, or 96 hours of rest.

CHAPTER II

RECOVERY IN TRAINED FEMALES AFTER AN EXHAUSTIVE RESISTANCE TRAINING PROTOCOL

Abstract

The purpose of this investigation was to examine the recovery capabilities of 10 resistance-trained females (ages 19-35) following three sets to failure for eight exercises. Recovery was measured as the number of repetitions performed at baseline compared to the total following 24, 48, 72, or 96 hours of passive recovery. Soreness was considered using a 100-mm visual analog scale (VAS). After 24 hours, the group mean (10.0 ± 1.1 reps) was similar ($p > 0.05$) to baseline (10.7 ± 0.5 reps). But at 48 hours and 72 hours, the group performed significantly better (11.5 ± 1.3 $p = 0.01$; 11.4 ± 1.2, $p = 0.00$ reps, respectively) than at 24 hours. For all recovery periods, soreness was significantly higher than baseline ($p > 0.05$), peaked at 24 h, declined over time, and at 48 hours, was significantly correlated to the group mean for repetitions ($r = -0.77$, $p = 0.01$). Large inter-subject variability existed across all recovery periods for all variables. The findings suggest trained females can recover more within 24 hours following an exhaustive resistance training protocol. Women were able to perform similarly to baseline at all time points despite experiencing a significant level of soreness.

KEY WORDS: weight lifting, fatigue, gender, performance testing

Introduction

As of 2008, over 400,000 athletes participated in National Collegiate Athletic Association (NCAA) sponsored sports. These athletes are regularly exposed to strenuous training regimens that include sport-specific practice and a strength and conditioning program. Often, as the main components of their conditioning approach, strength coaches include intense resistance training and power lifting. A bout of heavy resistance exercise results in acute neuromuscular fatigue (Hakkinen, 1993). The ensuing fatigue has often been characterized as a reduced ability to exert maximal voluntary contraction (MVC) force.

Many purport that fatigue has both central and peripheral sources. Central fatigue involves a reduction in muscle fiber recruitment or firing frequency, and peripheral fatigue relates primarily to depletion of energy substrates, disruption of the contractile apparatus, and accumulation of deleterious exercise by-products (Linnamo, Hakkinen, & Komi, 1998). Much of the research and consideration for training athletes has revolved around the conditioning aspect of the training plan. Consequently, recovery from fatigue between exercise sessions, sometimes referred to as “training recovery”, is less understood (Bishop, Jones, & Woods, 2008).

Typically, collegiate teams must train and lift on consecutive days due to the NCAA’s rule prohibiting sport administrators from having more than 20 hours of mandated practice time per week. One issue is whether these young men and women are able to fully recover in the 24-h period prior to the subsequent training session. Over time, if an athlete continues to partake in strenuous workouts without getting the rest needed to reverse the fatigue associated with the previous workout session, he/she may become over-trained. The overtraining syndrome can result in poor performance, severe fatigue, extreme muscle soreness, disturbed sleep patterns, mood changes, immune system deficits, as well as, overuse injuries (Kentta & Hassmen, 1998).

In light of recovery’s importance related to over-training, McLester, et al., 2003 evaluated the time-course required for well-trained, recreational male lifters to fully recover following an exhaustive training session. The investigators measured recovery in 10 male participants by comparing the mean number of repetitions performed in the first of three sets of eight resistance exercises during a baseline workout against that of an identical workout following recovery periods of various durations (24, 48, 72, or 96 hours). None of the subjects were able to fully recover in less than 48 hours. From the individual data, the investigators found that 40% of the participants reached full recovery after 48 hours. After 72 hours, 80% of the participants could repeat their baseline performance but one subject was still not recovered and another had fallen below his 48 h performance. After 96 hours, all of the subjects except one were recovered and others had begun to decline in performance back towards baseline.

In another investigation, Raastad and Hallen (2000) investigated varying intensity workouts and recovery in 10 male strength athletes. The participants first performed a high-intensity workout with 100% of their 3-repetition maximum (3-RM) for back squats and front squats. They combined these two lifts with knee extensions at 100% of their 6-RM. The participants also performed a moderate intensity workout at 70% of the high intensity workout with the same number of repetitions. The investigators found that it required 33 h before the subjects could replicate their baseline measurements for force and squat jump height following the high-intensity workout. The aforementioned studies included only male participants, so the recovery capabilities of women remain unknown.

In research investigations involving isometric contractions, females have demonstrated an increased resistance to fatigue compared to males (Clark, Collier, Manini, & Ploutz-Snyder, 2005; McLester et al., 2003; Fulco, et al., 1999; Hakkinen, 1993; Hunter, Griffith, Schlachter, & Kufahl, 2009; Linnamo, et al., 1998; Stupka, et al., 2000). Females also appear to experience less muscle damage and delayed onset muscle soreness relative to men (Kendall & Eston, 2002; Tiidus, 2000). Although differences in muscle distribution and force generation may explain some of these differences in men and women, it is thought that the higher estrogen level of females may offer some advantage during resistance training over their male counterparts. Estrogen has been shown to stabilize muscle cell walls thus reducing damage and possess anti-oxidant properties that reduce inflammation. It has also been suggested that due to a lower volume of muscle in women versus men, the global damage associated with working muscles is less. Komulainen et al. (1999) examined gender differences in the disruption of specific structural proteins of muscle, along with muscle fiber swelling (indication of inflammation) at various time points up to 96 hours following downhill running. Male subjects showed significantly more loss of structural proteins, derangement of muscular architecture, and fiber swelling compared to females. The onset of these deleterious effects in males was also significantly earlier, which has been suggested is the result of ischemia due to contracting musculature closing off blood vessels as pressure in the interstitial space rises above that inside the vessels. Although, more dynamic in nature, the contraction type associated with this protocol was eccentrically biased and does not readily transfer to the typical workout used by athletes.

Clark et al. (2003) found that women could maintain an isometric back extension at 50% of their MVC force significantly longer (146.0 ± 10.9 vs. 105.4 ± 7.9 s) than their male counterparts. However, they were similar during an isotonic task at the same percentage of MVC (24.3 ± 3.4 vs. 24.0 ± 2.8 repetitions, for women and men, respectively). To some degree, these findings demonstrate that the differences in male and female fatigue resistance may be linked to the chosen exercise paradigm. In a later investigation, Clark et al. (2005) examined muscle fatigability differences in men and women while participants performed a sustained knee extension at 25% of maximal force. Women had a longer time to task failure (214.9 ± 20.5 vs. 169.1 ± 20.5 s) when compared to men.

While much research has investigated muscle fatigue characteristics in men versus women, the literature is sparse concerning recovery in trained females while utilizing dynamic, resistance training with both concentric and eccentric contractions. Many studies have used males exclusively (McLester et al. 2003; Jones et al. 2006; Rastad et al., 2000) or untrained females (Kraemer, Staron, et al., 1998; Sewright et al., 2008) to investigate recovery. With little known regarding recovery in trained females, an accurate time-course for return to exercise has yet to be determined. Therefore, the purpose of this study was to measure the ability of females to replicate their weight-lifting performance after an exhausting, resistance training session within a specified recovery period (24, 48, 72, or 96 hours). We hypothesized that they would be able to replicate the total number of repetitions performed in the baseline exercise session during all subsequent lifting sessions. Additionally, the time course of muscle soreness onset and disappearance was investigated. This secondary objective was utilized to characterize the relationship between the degree of muscle soreness and the accompanying loss in work capacity. It was hypothesized that there would be a significant increase in muscle soreness that would dissipate within the 48 h period following the exercise protocol.

Methods

Participants and Recruitment

Healthy women (n = 10) ages 19-35, who self-reported regular participation in resistance exercise (3+ times per week/all major muscle groups) for the last two months, with the exception of competitive lifters, were recruited for this study. Subject characteristics are shown in Table 1.

Familiarization and Pre-Testing

All participants completed a physical activity readiness questionnaire (PAR-Q), a medical history questionnaire, and a blood pressure screening to help ensure they were low risk for exercise according to the American College of Sports Medicine (ACSM) risk stratification guidelines (American College of Sports Medicine., Thompson, Gordon, & Pescatello, 2010). Height and body weight were measured on a stadiometer and beam-balance scale (Detecto, Webb City, MO). Body mass index was calculated from these measures. A three-site (tricep/mid-thigh/suprailliac) skinfold measurement (Lange Caliper, Beta Technology Inc., Deer Park, NY) was taken in accordance with ACSM guidelines (American College of Sports Medicine., et al., 2010) to estimate body fat percentage (Jackson and Pollock, 1985), which permitted calculation of lean body mass.

Only women with a regular menstrual cycle and who were on a monophasic birth control prescription (for those who were using birth control) were included in the participant pool. This requirement was added to help control for hormone variations among subjects. Participants were instructed not to participate in any other resistance training activities other than the testing protocol during the duration of the study and were also instructed to maintain dietary habits as close as possible to those before the study. During the pretest session, participants also completed a questionnaire outlining previous and present exercise experience to assure the sample was experienced enough to qualify as required for inclusion in the study. This questionnaire provided information regarding exercises incorporated into the participants' typical workout sessions and the level of resistance commonly used for those exercises. Written informed consent, in accordance with the procedures for the protection of human subjects set forth by the local Institutional Review Board, was obtained before testing.

During session I, participants performed a 10-repetition maximum (10-RM) for eight different weight lifting exercises covering most major body parts. The eight lifts and accompanying muscle groups affected were as follows (no particular order): seated upright bench press – pectoralis major, seated upright shoulder press – deltoids, seated elbow extension (triceps press) – triceps brachii, seated elbow flexion (biceps curl) – biceps brachii, seated arm pull-down (lat pull down) – latissimus dorsi, supine hip extension (leg press) – gluteus maximus and quadriceps, prone knee flexion (leg curl) – hamstrings, and seated knee extension (leg extension) – quadriceps.

Each exercise was demonstrated with proper technique to help promote safe performance of each lift. In preparation for determining the 10 RM, subjects warmed up for each exercise with a light load that would easily allow ~15 repetitions. To determine the 10-RM, subjects lifted a self-selected initial weight and resistance was increased by 2.8 to 5.7 kg (depending on difficulty) for each of the lifts until approximately a 10-repetition max was elicited (9-11 RM acceptable). Two to four minutes of rest were provided between trials to allow for adequate recovery. All l0RM tests were supervised by the same experienced technician to make sure the 10-RM was found within 3 trials and that the testing was consistent across subjects. If the participant failed to obtain the 10-RM within the first three attempts, the participant went on to the next exercise, and returned to the original exercise at the end of the test session for another three attempts. If unsuccessful on this follow up attempt, the participant was asked to return one week later to allow for dissipation of any soreness and to repeat the 10-RM process. Once found, this 10-RM weight was used for all training sessions that followed. Each subject was then randomized to a counterbalanced treatment sequence. Participants were given detailed verbal and written instructions on pre-trial nutritional intake, as well as, provided a food log to record daily food consumption. The aim of this procedure was to keep daily nutritional intake as similar in content and portion size as possible throughout the 10-day testing period. If a participant showed a 20% change in caloric intake in either direction (calculated on www.mypyramid.gov) compared to their baseline session, their training session was re-scheduled.

Procedures for Exercise Training Sessions

Participants were instructed to avoid consuming food or beverages, other than water, two hours prior to testing, caffeine for four hours prior to testing, and alcoholic beverages 24 hours prior to testing. Participants returned 24, 48, 72, or 96 hours after the baseline workout (session II) to perform sessions III-VI with the recovery time between trials assigned to subjects randomly but in counterbalanced order. Counterbalancing was used to partially account for any training effects that might accrue from any particular timing of resistance training sessions. Participants completed each of the five different sessions at the same time of day.

Session II was the initial baseline test session used to create fatigue and any soreness that might occur. Subjective recovery was evaluated just prior to test sessions III-VI using a Perceived Recovery Scale (PRS). On this scale, the participant subjectively indicated recovery from the previous exercise session based on a scale from 0 to 10 (0= Very poorly recovered, 10= Very well recovered). Any soreness produced by the previous workout session for sessions III-VI was evaluated using a 100 mm visual analog scale where 0 = little or no soreness and 100 = extreme muscle soreness. These trials began at least three days after the predicted end of the participant's last day of menses and ended at least three days prior to the predicted beginning of menses. Sessions were conducted over a strict 10-day schedule due to the specific recovery duration requirements.

The 10-RM weight load established in the pretest was the load used for each set of exercise in all five testing sessions (sessions II-VI). After arriving at the first weight machine, participants performed a warm-up set with approximately 60% of the 10-RM established for each exercise during the pre-test session (session I). Before beginning the warm-up set or test trial, researchers reminded participants of the correct lifting technique. Afterwards, participants were reminded to lift until they felt momentary muscular failure. Momentary muscular failure was defined as the inability to perform a complete, non-assisted repetition. However, supervisors gave no verbal encouragement or physical assistance, in order to keep the testing environment as consistent as possible. Investigators monitored and recorded the number of whole (full range of motion) repetitions that were performed. The exercises (mentioned previously) were performed using Cybex machines (Lumax, Ronkonkoma, NY). The subjects performed three sets to momentary muscular failure of each exercise before moving to the next exercise. Sets and exercises were separated by a one-minute rest period.

The mean number of successful repetitions accomplished by the participant during the first exercise session was the reference standard for the subsequent sessions. After each set of each exercise, the participant was asked to give a rating of the level of perceived exertion (RPE), (Borg 6-20 Scale)(Borg 1974) to determine set-by-set and overall subjective intensity. All rating scales were attached to the reverse side of the investigator's clipboard and visible to the participants. A stopwatch was used to time and standardize the rest interval between sets at one minute for all participants. This procedure was used to ensure participants all had a uniform acute recovery break to standardize work intensity.

Participants were required to perform as many repetitions as possible for each set of each lift in the test sessions that followed (24, 48, 72, and 96 hours after the previous session, counterbalanced among subjects). The original randomly established order of the eight exercises for each individual during session I was held constant for all subsequent sessions. Participants exercised at the same time of day for all sessions.

Statistical Analyses

The totals for the first set of each exercise was used for statistical analysis to minimize error due to variability in rest periods between lift sets and effects of the first set on subsequent sets (e.g. number of reps in 2^{nd} set affected by 1^{st} set). Therefore, the first set was assumed to be the most representative measure of performance. The second and third sets were performed to generate fatigue associated with a full workout and thereby permit the evaluation of the different recovery durations being investigated. All analyses were performed using SPSS for Windows statistical program (v. 18.0). A General Linear Model (GLM) with repeated measures was performed on all variables. The assumption of sphericity was tested by the Mauchly test of sphericity. Any violations of this assumption were corrected using Greenhouse-Geisser adjustment. The GLM was followed by post hoc tests for all significant effects. *Post hoc* tests were performed with paired-sample *t*-tests using the Bonferroni correction technique to detect which trends were significant for the recovery of each lift. Additionally, some variables were analyzed using a Pearson product-moment correlation coefficient to discover their association with other variables of interest. Alpha level was set at 0.05 for all hypothesis tests. Data were expressed as mean ± *SD.* All assumptions for the use of a GLM were met prior to analysis. An a priori power analysis indicated that to achieve statistical power equal to 0.80 with an effect size equal to 1.0, ten participants would be needed. This requirement was met.

When training athletes, individual differences are important and can be utilized. Consequently individual data were examined and recovery was expressed as a percentage of the total group. Recovery was deemed sufficient when the baseline total could be replicated.

Results

Figure 1 shows the mean delta score for total repetitions of each participant across all recovery periods.

Based on group means, after 24 h of recovery participants performed a similar number (10.0 ± 1.1 reps, $p = 0.24$) of repetitions compared to the baseline (10.7 ± 0.5) (session I). After the 48 h recovery period, participants showed a performance similar to baseline ($p = 0.38$), however the total at 48 h (11.5 ± 1.3 reps) was significantly higher ($p = 0.01$) than the number of repetitions performed after the 24 h recovery period (10.0 ± 1.1 reps). Following recovery of 72 h (11.4 ± 1.2 reps) and 96 h (11.0 ± 1.1 reps) group mean data showed that participants continued to perform similarly to their baseline performance, ($p = 0.40$ and $p = 0.82$, respectively). However, compared to 24-h of recovery, at 72 hours participants showed a significantly higher group mean (11.4 ± 1.2 reps, $p = 0.004$).

Figure 2 depicts performance compared to baseline as represented by means and standard deviations of the number of repetitions, for the upper- and lower-body exercises. As can be seen, the tendencies of the upper- and lower-body performance appeared virtually identical at baseline and at 24 hours recovery (mean = 10.6 ± 1.5 repetitions during exercise session I vs. 9.9 ± 2.1 after 24 hours recovery for the upper body; 10.7 ± 1.9 repetitions during session I vs. 10.3 ± 2.5 at 24 hours for the lower body) and showed no significant difference ($p = 0.69$ at baseline and $p = 0.46$ at 24 h) between body regions at either time point. After 48 hours of recovery, the mean for lower body was similar to that of the upper-body (11.5 ± 2.8 for lower body at 48 hours vs. 11.4 ± 2.0 for the upper body exercises at 48 hours of recovery, $p= 0.96$). Following 72 hours of recovery, both the upper- and lower-body mean repetition totals were the same (11.4 ± 2.0 repetitions for the upper-body vs. 11.4 ± 2.6 repetitions for the lower-body, $p = 0.98$). Lastly, both upper- and lower-body exercises decreased towards baseline (10.9 ± 2.2 repetitions for upper-body exercises and 11.2 ± 3.3 repetitions for lower-body exercises) but were not significantly different ($p = 0.71$) following 96 hours of recovery.

Changes in global soreness ratings are presented for each body part in Figure 3a. All measurements represent participant responses on a 100-mm visual analog scale with the anchors 0 (no soreness at all) and 100 (extreme muscle soreness). The obvious trend was that soreness for each body part decreased as recovery duration increased. In Figure 3b, it can be seen that ratings of overall body soreness showed a similar trend as recovery time between sessions increased. Overall soreness at 24 h and 48 h were not significantly different (32.3 ± 18.3 mm after 24 h vs. 21.7 ± 10.7 mm after 48 h, $p = 0.86$). However, participants reported significantly lower levels of overall body soreness after 72 h of recovery when compared to 24 h of recovery (32.3 ± 18.3 mm after 24 h vs. 10.0 ± 6.9 mm after 72 h, $p = 0.02$). Overall body soreness was significantly less after 96 h of recovery compared to both 24 h and 48 h of recovery (32.3 ± 18.3 mm vs. 4.9 ± 3.6 mm, $p = 0.004$ and 21.7 ± 10.7 mm vs. 4.9 ± 3.6 mm, $p = 0.01$), respectively. There was no statistical difference for overall body soreness between 72 h and 96 h of recovery. Correlation analysis revealed that mean repetitions performed at baseline were significantly and positively related to mean repetitions after 24 h ($r = 0.93$, $p = 0.000$) and 48 h ($r = 0.69$, $p = 0.03$) of recovery. Not surprisingly, mean repetitions following 24 h recovery showed a moderate and positive relationship with mean repetitions after 48 h ($r = 0.75$, $p = 0.01$) and 72 h ($r = 0.76$, $p = 0.011$) of rest. Additionally, there was a relationship between the number of repetitions participants performed at 72 h post-exercise with mean repetitions following a recovery period of 96 h ($r = 0.75$, $p = 0.01$). The mean score for overall body soreness after 48 h of recovery was shown to be significantly and negatively ($r = - 0.77$, $p = 0.010$) correlated with the 48 h mean repetition total (those who were less sore, did more repetitions). Mean reps performed after 24 h of recovery showed a significant and negative relationship ($r = -0.76$, $p = 0.02$) with the mean overall RPE for the 24 h recovery exercise session (those who reported a lower perceived exertion did more reps). As expected, caloric intake did show great variability between participants. However, individuals did not significantly ($p > 0.05$) differ between sessions when compared to themselves.

Discussion

The purpose of the current investigation was to examine the muscular endurance recovery patterns in women following an intense, all-body resistance training session. It was expected that the female participants would be able to replicate the number of repetitions performed during their baseline workout after a 24-h recovery period and would demonstrate a similar pattern in subsequent workouts with a 48-h, 72-h, or 96-h rest period. In agreement with our hypothesis, the results indicate that, as a group, the participants' mean performance was not significantly different for any of the investigated recovery periods when compared to their initial baseline workout. Of additional interest, the participants were actually found to be increasing in the number of mean repetitions performed at 48 h and 72 h post-exercise, compared to 24 h post-exercise. It was also evident that this protocol detected variations in individual muscular endurance as evidenced by the variability of findings of the individual data.

A second purpose was to characterize the relationship between the degree of muscle soreness and the accompanying loss in work capacity. Soreness ratings were statistically higher ($p \leq 0.05$) than baseline at all recovery points which disagrees with our hypothesis that muscle soreness would be similar to baseline within 48 hours. As previously mentioned a moderate but significant correlation ($r = -0.77$, $p = 0.01$) was found between overall body soreness following

48 h of recovery and mean repetition performance following the same time period. This was the only time point where mean repetitions and soreness had a significant relationship. One possible explanation for why this occurred at the 48 h mark was that this is the only time mean soreness declined concurrently with a significant increase in repetitions ($p = 0.007$). Thus an artificially high correlation may have resulted from such a scenario.

This is the first study to look at the time-course of recovery in trained females following a typical, albeit intense, resistance training workout with both concentric and eccentric contractions. Most recovery investigations to this point have used isometric (Clark et al., 2003; Hunter et al., 2009) contractions, eccentric only contractions (Hubal, Rubinstein, & Clarkson, 2007; Johansson, Lindstrom, Sundelin, & Lindstrom, 1999; Rinard, Clarkson, Smith, & Grossman, 2000; Stupka, et al., 2000), or electrical stimulation (Hakkinen et al., 1993) to create fatigue. Additionally, other resistance training investigations have used untrained (Johansson et al., 1999; Kraemer et al., 1998) subjects. Thus comparisons with the current literature are largely indirect.

The results of our investigation do not support the findings of some recent studies. For example, Rinard et al. (2000) observed a 27% strength deficit at 168h post-exercise. In this study, the female participants performed 70 maximal lengthening (eccentric) contractions with one contraction being performed every 15 s with a five minute break at the midway point. Our resistance training paradigm obviously impacted the muscles differently.

Our findings also do not support Hubal et al (2007) wherein the investigators divided female participants into “low-fatigue responders” and “high-fatigue responders” based on their level of fatigue 24 h after performing five sets of 10 maximal lengthening (eccentric) actions.

The investigators found that it took 72 h for the low responders to recover to pre-exercise levels of maximal voluntary contraction force, whereas high responders took 96 h to return to baseline.

One possible explanation for the differences between the current investigation and the findings of Rinard et al. (2000) and Hubal et al. (2007) is the difference in contraction type used as the fatigue stimulus. In the first two studies, the contractions were eccentric-only, whereas in our investigation, the actions were concentric and eccentric. It has been shown that eccentric contractions cause higher tension and stress on muscle fibers than concentric ones (Enoka, 1996) resulting in increased soreness, increased force deficits, and a longer duration of force loss. This makes direct comparisons between the three studies more difficult.

In another investigation by Johansson et al. (1999), 10 healthy females experienced a reduced maximal contractile force for 96 h after performing 10 sets of 10 maximal eccentric contractions of the knee flexors with 30 s rests between sets. In addition to the exercise difference, the Johansson et al. (1999) study participants were untrained, whereas the women in the current study were lifting for three or more hours per week. It has been shown that the initial improvements in resistance training performance can occur within as little as 48 h following a single resistance training session as the result of neural adaptations (Gabriel et al. 2006). Without the requirement of being resistance-trained, the repetition totals achieved in study sessions following the initial baseline session, could give the impression that the subjects experienced complete recovery when in actuality it was simply the result of improvements due to training adaptations. In their study, the number of repetitions performed could be attributed to: 1) increased neural drive from the central nervous system to the working muscles, 2) more efficient/synchronized firing of the motor units that make up an active muscle 3) increased activation of synergistic (assisting) muscle groups to the main muscle group being activated, along with, inhibition of antagonistic (opposing) muscle groups, and 4) increased motor unit firing rates. All of these adaptations have been shown to occur in subsequent lifting sessions within 48 hours (Gabriel, et al., 2006).

In our study, as expected, great variability did exist in the recovery patterns of individuals. For example, only one participant (10%) was able to completely replicate the workout (i.e. fully recovered) after 24 h, despite that the group mean was not significantly different. Our finding indicates that only one of the ten participants in our investigation would be able to replicate consecutive day workouts without beginning the second workout partially fatigued. Ultimately, the practicality of coaches and trainers utilizing intense workouts within 24 h would need to be examined in light of the current results and the potential for leading athletes to an overtrained or stale condition. Seventy-percent of the participants were fully recovered after 48 h. Two of the three subjects who fell below baseline at 48 hours, were unable to make a full recovery until they were given 96 hours before the subsequent workout. The other subject who was under-recovered at 48 hours was able to duplicate her baseline numbers with 72 h between sessions, but then experienced a decline below baseline in repetition mean with a 96 h recovery period. After 72 hours recovery, 70% of the participants were recovered, one of which was not recovered at 48 h and one subject who repeated their baseline numbers at 48 h, experienced another decline below baseline.

The current findings may offer some evidence that women exhibit enhanced recovery when compared to their male counterparts. In 2003, McLester et. al performed an investigation with recreationally trained, 18-30 year old men. On average, the participant group in the McLester study was statistically under-recovered until 48 hours post-exercise. In the current investigation, there was no significant decline in repetition mean between baseline and any recovery period.

However, the most interesting comparisons between McLester et al., (2003) and the current investigation came from examining the individual differences in recovery between the two participant pools. Specifically, at 48 h post-exercise in our investigation, 70% of participants had made a complete recovery that resulted in these women performing a statistically ($p > 0.05$) higher number of repetitions compared to 24 h recovery. Comparatively, only 40% of the male participants in the McLester, et al. (2003) investigation were recovered at the same time point. After 72 h of recovery, 80% of the participants in the McLester, et al. (2003) study were recovered and of the remaining two subjects, one was still not fully recovered and the other participant was actually digressing below his 48-h performance (possibly detraining). The current investigation shared similar characteristics, in that 70% of the participants were recovered, one participant was still below baseline, one participant who had not been recovered at 48 h was now recovered at 72 h, and lastly, one participant who was above baseline at 48 h had fallen to below baseline (possibly detraining).

This large individual variation persisted when the participants lifted following 96 h of recovery. Three participants in the McLester et al. (2003) study were showing improvements, six had plateaued or began to decline, and one subject was still below baseline. In our investigation, one participant that had been recovered at 48 h and 72 h had fallen below baseline, one participant who had been previously under-recovered, replicated their baseline numbers, and one participant who had recovered after 48 h of rest was again below baseline. These observations illustrate the individual variability that exists regarding recovery. In an attempt to evaluate this practical approach to measuring recovery, Jones et al. (2006) replicated the

McLester et al. (2003) study and found, similarly, that none of the male participants were able to recover fully in less than 48 hours. However, the investigators found good stability in establishing recovery times for multi-muscle workouts across individuals, which offers some validity for the use of this protocol for evaluating male athletes' recovery patterns. The same protocol in the current investigation was able to identify varying recovery times for trained females and thus may have a similar utility with female athletes.

The high levels of variability demonstrated by both genders when recovering from strenuous resistance exercise illustrate the need for coaches and personal trainers to develop training plans that take into consideration their athletes' and clients' unique recovery capabilities. Often coaches and trainers provide one program or one approach to training and recovery for their athletes. Although the program that is provided may work well for some of the athletes, for others it can lead to detraining/plateauing because they recover more quickly and need another training stimulus sooner. It can also lead to overtraining in others who demonstrate a slower time to full recovery. The current protocol may provide a functionally sound and practical way of assessing athletes and clients on a regular basis, in order to make the most precise, individualized recommendations possible.

One of our limitations was our lack of absolute control over our participants. It is possible that the variability in previous training habits, session duration, frequency, and intensity among participants may account for some of the variability observed in this study. However, all participants were at least as experienced as an *a priori* requirement for inclusion in the investigation. Also diet was not controlled among participants. Therefore the potential exists that some participants did not receive a similar quality of macronutrient intake following the strenuous protocol. Participants maintained a food log to at least demonstrate that caloric intake was similar among their bouts even if not comparable to their fellow exercisers. Variations in sleep and activity patterns may have contributed to fluctuation in performance as well, since the pool consisted of college students with varying time demands over the course of the investigation. All participants were asked before beginning each test session whether they had received adequate rest and were to the best of their knowledge physically and mentally prepared to exercise with an all-out effort. All participants indicated for all sessions that they met these two criteria and acknowledged as such by initialing their original informed consent.

In conclusion, the main findings were that resistance trained females, in general, may respond well to consecutive day workouts, followed by a 48 h rest period to maximize adaptations. It also appears, at least in the current participant pool, that significant levels of muscle soreness are associated with a reduction in muscular endurance after 48 hours of recovery only as demonstrated by a moderate correlation. Additionally, 72 h and 96 h of rest may result in detraining among some well-trained females and thus is not recommended unless indicated through a functional evaluation such as the one incorporated in the present study.

The protocol used in the current investigation was able to delineate the individual variability in muscular endurance recovery among resistance trained females. This protocol was able to consistently create a measurable degree of soreness and fatigue even among the experienced participants.

Large degrees of variability exist among individuals, even if their training status is similar. This finding further illustrates the necessity for a useful and ecologically valid process for evaluating recovery capabilities in females. Ultimately, these evaluative procedures may help coaches and trainers maximize potential improvements in their athletes from conditioning and training programs without placing them in a situation that leads to overtraining. This paradigm may prove to be a useful tool to evaluate the time course required for complete recovery from fatigue associated with intense resistance training. A better understanding of the individual female's rest needs may help to avoid the overtraining syndrome and potential injury.

Additional studies are warranted to further evaluate the validity and reliability of muscular endurance assessment with the current protocol. Also, this particular protocol may lend itself well to the evaluation of ergogenic aids in conjunction with resistance training. Lastly, the utility of the current protocol needs to be evaluated with elderly subjects across both genders to elucidate what changes in recovery duration and quality may occur following menopause or sarcopenia.

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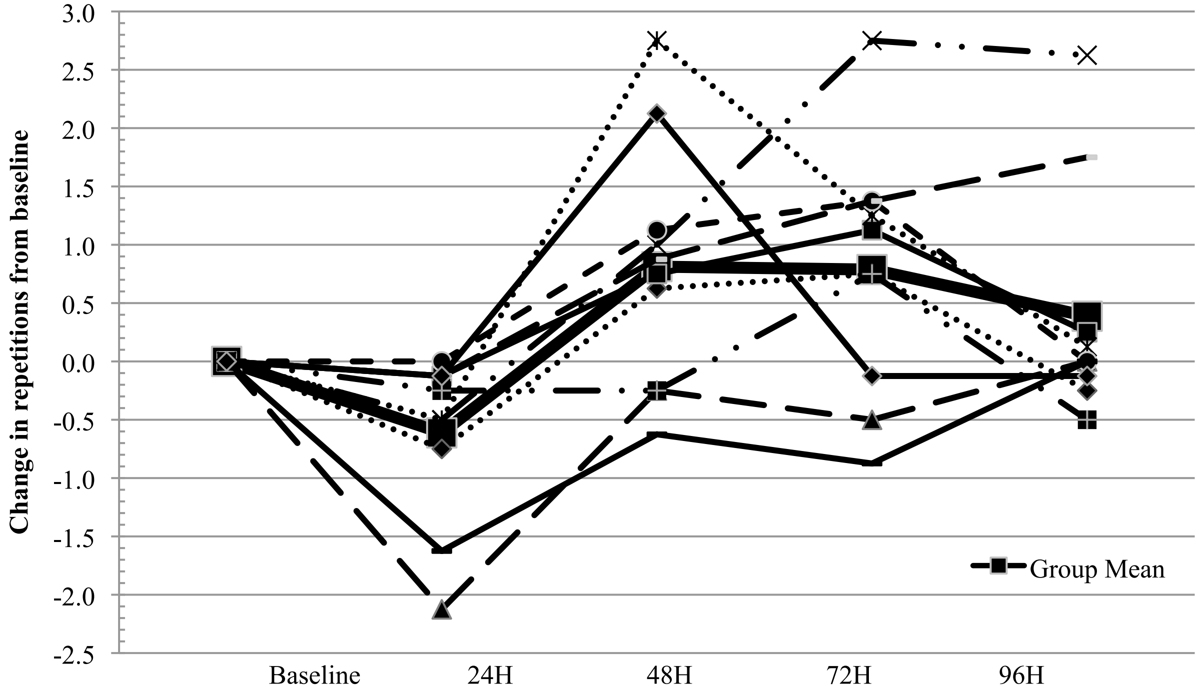
Tables

Table 1 – Mean (SD) participant demographics and training history (n=10).

Age (years)	21.2 (1.4)
Height (cm)	163.1 (4.6)
Weight (kg)	58.1 (8.7)
Body fat (%)	21.9 (4.9)
Body Mass Index (kg/m^2)	21.7 (2.6)
Systolic Blood Pressure (mmHg)	98.4 (5.7)
Diastolic Blood Pressure (mmHg)	66.4 (3.7)
Training history	
• Training (years)	3.3 (2.8)
• Frequency (days/wk)	3.2 (0.6)
• Sets per exercise	2.8 (0.6)
• Reps per set	12 (2.3)
• Length of typical workout	56.7 (16.0)

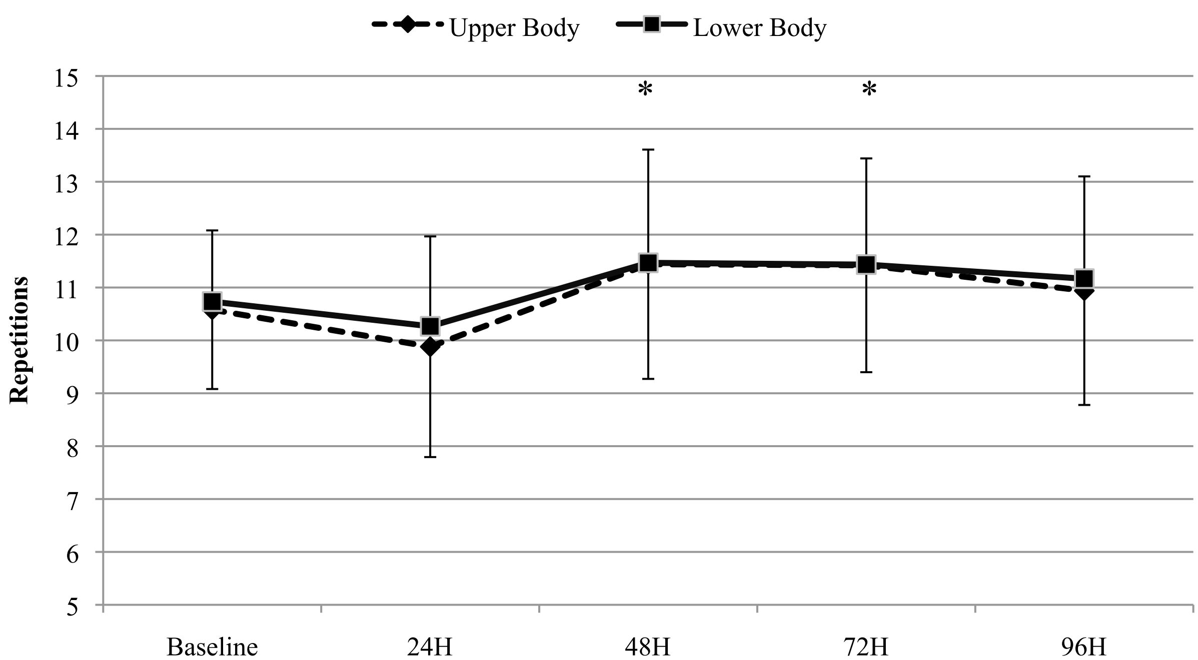
Figures

1.



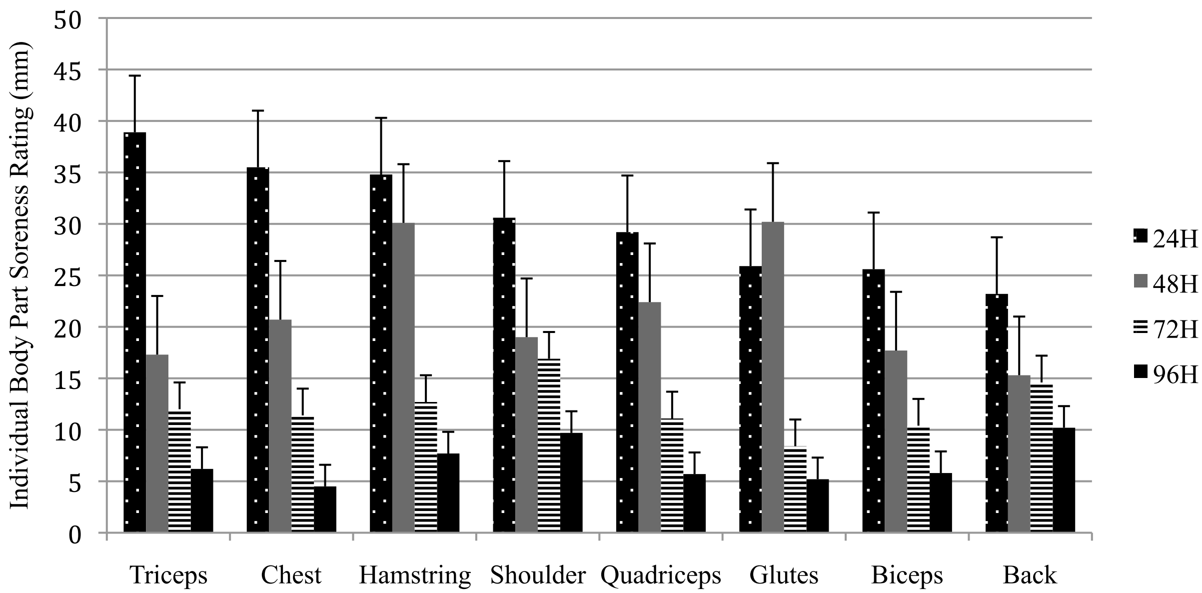
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
Change in repetitions from baseline
Group Mean
Baseline
24H
48H
72H
96H

2.



Upper Body
Lower Body
15
14
13
12
11
10
9
8
7
6
5
Repetitions
*
*
Baseline
24H
48H
72H
96H

3a.


Individual Body Part Soreness Rating (mm)
50
45
40
35
30
25
20
15
10
5
0
Triceps
Chest
Hamstring
Shoulder
Quadriceps
Glutes
Biceps
Back
24H
48H
72H
96H

3b.

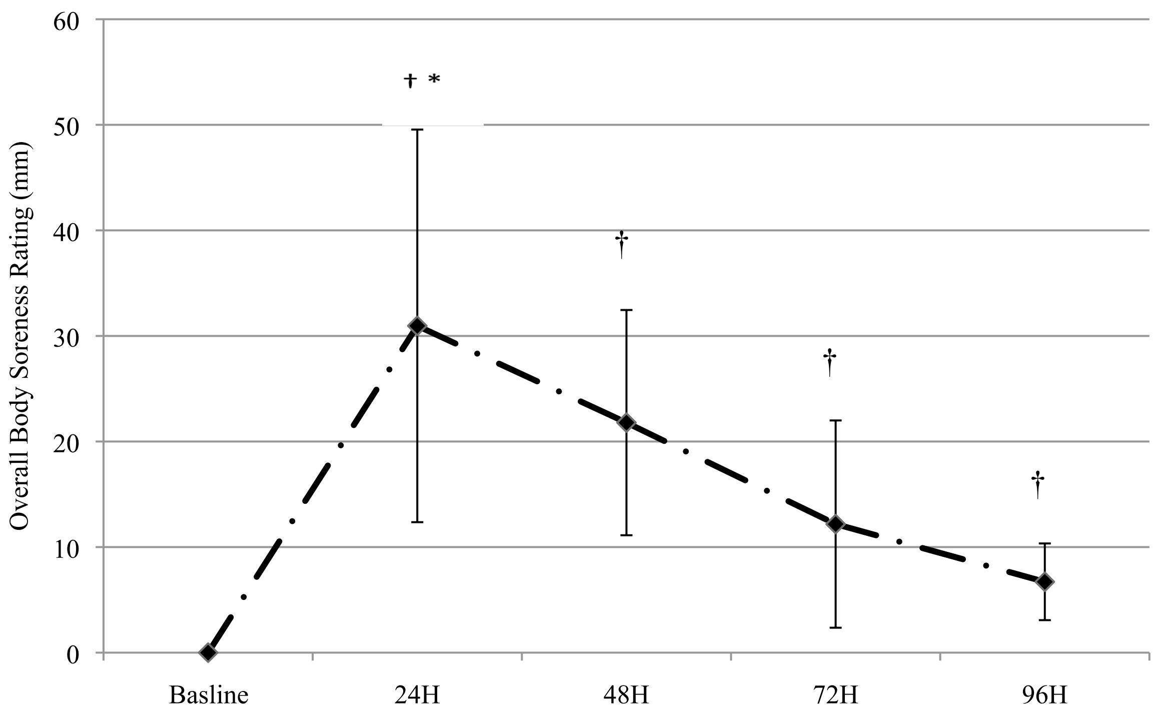

Overall Body Soreness Rating (mm)
60
50
40
30
20
10
0
† *
†
†
†
Basline
24H
48H
72H
96H

Figure Captions

Figure 1. – Change in mean repetitions (eight exercises) for individual and group mean compared to baseline after different recovery intervals ($n = 10$).

Figure 2. – Change in performance (mean ± SD) since the previous test period for upper- and lower-body exercises. No significant difference existed ($p > 0.05$) between body regions at any time point ($n = 10$). *Significantly different ($p \leq 0.05$) from session I (baseline).

Figure 3. – Change in individual body part soreness rating (panel A) and overall body soreness rating (panel B) at 24 h, 48 h, 72 h, and 96 h post-exercise ($n = 10$). †Significantly higher ($p \leq 0.05$) than baseline. *Significantly higher ($p \leq 0.05$) than 96 h

CHAPTER III

EFFECT OF POST-EXERCISE CONSUMPTION OF A CARBOHYDRATE-PROTEIN BEVERAGE ON RECOVERY FOLLOWING EXHAUSTIVE RESISTANCE EXERCISE IN TRAINED FEMALES

Abstract

The purpose of this investigation was to examine the recovery capabilities of nine resistance-trained females (ages 19-35) following three sets to failure for eight exercises with post-exercise consumption of a carbohydrate-protein (CHO-PRO) or a carbohydrate-only (CHO-ONLY) beverage. Recovery was measured as the number of repetitions performed at baseline compared to the total following post-exercise consumption of CHO-PRO or CHO-ONLY and 24 hours of passive recovery. After 24 hours, the group mean for CHO-PRO (10.5 ± 1.6 repetitions) was similar ($p > 0.05$) to CHO-ONLY (11.3 ± 2.0 repetitions). Soreness was also measured using a 100-mm visual analog scale. For both CHO-PRO and CHO-ONLY, soreness was significantly higher than baseline ($p > 0.05$). Mean soreness for the treatments was not significantly different when using CHO-PRO or CHO-ONLY (33.6 ± 21.7mm vs. 25.8 ± 15.9mm, $p = 0.24$). Large inter-subject variability existed across both treatments for all variables. The findings suggest that the addition of protein to a carbohydrate beverage does not enhance recovery to a greater extent than an iso-caloric, carbohydrate-only beverage. Women were able to perform similarly to baseline with both treatments despite experiencing a significant level of soreness. Although group means were not significantly different between treatments, it may be advantageous to examine individual responses to supplementation when making decisions regarding use of CHO-PRO or CHO-ONLY.

KEY WORDS: supplementation, weight lifting, gender, protein synthesis

Introduction

Resistance exercise has been shown to stimulate muscle protein synthesis in both an absolute sense and relative to the rate of muscle protein breakdown (Miller et al., 2003). Consequently, through enhancement of the protein synthesis process, resistance training can be considered an effective way to increase lean muscle mass and strength in both young and older populations (Koopman & van Loon, 2009; Hurley et al. 2000).

But these helpful adaptations require an anabolic environment that results from a positive net protein balance (NPB). A person who consumes adequate daily meals, without the inclusion of strenuous exercise will typically exhibit a muscle protein mass that is unchanged. According to Burd et al. (2009), this situation occurs because the rate of muscle protein synthesis (MPS) and muscle protein breakdown (MPB) are similar, which produces an overall net protein balance (NPB) of zero. Following a bout of resistance exercise, there is a spike in muscle protein synthesis during the post-exercise recovery period lasting from 24-48 hours. However, in the absence of dietary protein the rate of muscle protein breakdown is increased to a greater extent. According to Borsheim et al. (2002), this scenario results in a negative overall NPB that leads to muscle wasting. Without adequate intake of calories and essential proteins, individuals experience a situation where the assembly of muscle protein is exceeded by breakdown. Dangin et al. (2001) state that a concomitant nutrient intake is therefore necessary to produce a positive NPB in order to avoid a shift to this catabolic state (Cribb et al., 2007).

Commercially available whey protein beverages, which typically contain some carbohydrates and a small amount of fat, have become an increasingly popular nutritional supplement used by professional, collegiate, and recreational athletes as part of their post-exercise recovery strategy. Kerksick et al. (2008) proposed that the synergistic effect of combining resistance training and carbohydrate-protein supplementation can: 1) increase muscle glycogen (energy storage), 2) offset muscle damage which may speed recovery, 3) facilitate greater training adaptations after either acute or prolonged supplementation with resistance training, 4) increase protein synthesis (regardless of whether the supplement was taken before or after exercise) with the greatest increases seen with ingestion both pre- plus post-exercise consumption, and 5) increase strength while improving body composition.

Enhanced strength recovery and reduced muscle soreness is important since, according to Cheung et al (2003), there is a direct relationship between orthopedic injuries and the functional deficiency seen with an under-recovered, sore athlete. Proposed reasons for this increased injury risk due to under-recovery are: a reduced range of motion, reduced cushioning lost with a decreased range of motion of the joint, decreased muscle coordination, increased stress on compensatory muscles, increased intensity at any given workload, and imbalance in the strength ratio between agonists and antagonists (Cheung et al., 2003).

Currently, nutritional investigations looking at the independent and combined recovery effects associated with ingestion of protein and carbohydrates after resistance training have used predominantly male participants (Esmarck, et al., 2001; Fujita, et al., 2009; Hartman, et al., 2007; Ivy, et al., 2002; Koopman, Beelen, et al., 2007; Koopman, Saris, Wagenmakers, & van Loon, 2007; Kraemer, Hakkinen, et al., 1998; Willoughby, Stout, & Wilborn, 2007). Even when females were included in the participant pool, no comparisons were made between genders (Tipton, Borsheim, Wolf, Sanford, & Wolfe, 2003).

In a review of sex-based differences in protein metabolism, (Burd et al., 2009) suggested the differences between young males and young females were minimal. Unfortunately, these claims were based on only a few investigations measuring the effect of CHO-PRO supplementation in females with resistance training (Rasmussen et al., 2000; Green et al., 2008). Additionally, the exercise protocols used in those studies, such as downhill eccentric running, unilateral knee extensions, and several sets of the same exercise for one muscle group do not necessarily reflect the typical workout used by recreational lifters or athletes. The inferences that can be gained from these investigations may not directly apply to exercise in which the workout involves contractions utilizing a concentric shortening phase immediately followed by an eccentric lengthening phase. Also, it has been shown in previous work by Campbell et al. (2010) that 9-out-of-10 well-trained females were unable to fully recover from a strenuous, all-body resistance-training workout within a 24 h period. This finding suggests the typical schema of consecutive day workouts by collegiate athletes may create a scenario that leads to overtraining in females. It would be helpful for these young women to seek interventions that could speed up the recovery process.

Currently, minimal information exists regarding the time required for a female athlete to recover from strenuous resistance exercise. There is a need to gain a clearer perspective on the time course for recovery in women following a bout of intense resistance training. This information could assist with the creation of a training plan that maximizes the opportunity to make improvements while avoiding the deleterious effects of overtraining. Additionally, it would be beneficial to provide insight to strength coaches and sports nutritionists of the utility of a CHO-PRO beverage to enhance recovery from fatigue and reduce soreness. Therefore, the aim of this study was to investigate the effect of a post-exercise CHO-PRO or CHO-ONLY beverage on 24-hour recovery in females following intense resistance exercise. It was hypothesized that, when consuming a CHO-PRO beverage compared to the CHO-ONLY beverage, the female participants would: 1) be able to replicate her baseline repetition mean (of eight exercises), 2) perform a significantly higher number of exercise repetitions, 3) report lower levels of soreness, and 4) demonstrate an improved perception of recovery.

Methods

Participants and Recruitment

Healthy women (n = 10) ages 19-35, who self-reported regular (three times per week/all major muscle groups) participation in resistance exercise over the last two months, with the exception of competitive lifters, were recruited for this study. Participants' physical characteristics and pre-investigation exercise habits are presented in Table 1.

Familiarization and Pre-Testing

All participants attended an orientation meeting that included determination of each participant's 10- repetition maximum on eight commonly used resistance exercises. Written informed consent in accordance with the procedures for the protection of human participants set forth by the local Institutional Review Board was obtained before testing. All aspects of the study and participants' rights were discussed and all participant questions were answered.

Participants were recruited from the student recreation center of a major university in the southeastern United States. During the pretest session, participants completed a questionnaire outlining previous and present exercise experience to assure the participant population was homogeneous and experienced enough to qualify for inclusion in the study. This questionnaire provided information regarding exercises incorporated into the participants' typical workout sessions and the level of resistance commonly used for those exercises.

All participants completed a physical activity readiness questionnaire (PAR-Q), a medical history questionnaire, and a blood pressure screening to help ensure they were low risk for exercise according to ACSM risk stratification guidelines (2010). Participants viewed a beverage ingredient form listing all ingredients that could be in either of the two test beverages. Participants also completed a taste aversion questionnaire and were excluded from the study if they had a strong aversion to consuming a carbohydrate-protein beverage or had an allergy associated with any of the ingredients. None of the participants in the current investigation reported a present or past eating disorder during screening.

Height and body weight were measured on a stadiometer and beam-balance scale (Detecto, Webb City, MO). Body mass index was calculated from these measures. A three-site (tricep/mid-thigh/suprailliac) skinfold measurement (Lange Caliper, Beta Technology Inc., Deer Park, NY) was taken in accordance with ACSM guidelines (2010) to estimate body fat percentage (BF) (Jackson and Pollock, 1985), which was used to calculate fat free mass.

Only women with a regular menstrual cycle and who were on a monophasic birth control prescription were included in the participant pool. This requirement was added to control hormone variations among participants. Participants were instructed not to participate in any other resistance training activities other than the testing protocol during the study and were also instructed to maintain dietary habits as close as possible to those before the study.

During session I, participants performed a 10-repetition maximum (10-RM) for eight different weight lifting exercises covering most major body parts. The eight lifts and accompanying muscle groups affected were as follows: seated upright bench press (pectoralis major), seated upright shoulder press (deltoids), seated elbow extension (triceps) triceps press (triceps brachii), biceps curl (biceps brachii), seated arm pull-down (latissimus dorsi), supine leg press (gluteus maximus and quadriceps), prone leg curl (hamstrings), and seated knee extension (quadriceps). These exercises were performed using Cybex machines (Lumax, Ronkonkoma, NY).

Each exercise was demonstrated with proper technique to help promote safe performance of each lift. In preparation for determining the 10-RM, subjects warmed up for each exercise with a light load that would easily allow ~15 repetitions. To determine the 10-RM, participants lifted an initial weight and increased resistance by 2.8 to 5.7 kg (depending on difficulty) for each of the lifts until approximately a 10-repetition max was elicited (9-11 RM acceptable). Two to four minutes of rest were provided between 10-RM attempts and exercises to allow for adequate recovery.

Each exercise was demonstrated with proper technique to help promote safe performance of each lift. In preparation for determining the 10-RM, subjects warmed up for each exercise with a light load that would easily allow ~15 repetitions. To determine the 10-RM, subjects lifted a self-selected initial weight and resistance was increased by 2.8 to 5.7 kg (depending on difficulty) for each of the lifts until approximately a 10-repetition max was elicited (9-11 RM acceptable). Two to four minutes of rest were provided between trials to allow for adequate recovery. All l0RM tests were supervised by the same experienced technician to make sure the 10-RM was found within three trials and that the testing was consistent across subjects. If the participant failed to obtain the 10-RM within the first three attempts, the participant went on to the next exercise, and returned to the original exercise at the end of the test session for another three attempts.   If unsuccessful on this follow up attempt, the participant was asked to return one week later to repeat the 10-RM process. Once found, this 10-RM weight was used for all training sessions that followed. Each subject was then randomized to a counterbalanced treatment sequence. Participants were given detailed verbal and written instructions on pre-trial nutritional intake, as well as, provided a food log to record daily food consumption. The aim of this procedure was to keep daily nutritional intake similar in content and portion size during exposure to the test beverages. All participants were within 20% of their baseline caloric intake (calculated on www.mypyramid.gov), in all subsequent exercise sessions.

Experimental Procedures & Exercise Protocol

Participants were instructed to avoid consuming food or beverages, other than water, two hours prior to testing, to ingest no caffeine for four hours prior to testing, and no alcoholic beverages twenty-four hours prior to testing. Each participant performed four trials. Two of the trials were used to create the fatigue and soreness stimulus for the follow-up exercise session. The two follow-up sessions were used to measure the effect of the test beverages on the subjective and quantitative recovery status of the participants.

After the initial "fatigue" session, participants received, in counterbalanced order, either CHO-PRO or CHO-ONLY immediately following the cessation of exercise. The participants returned twenty-four hours later to repeat the exercise protocol in the follow-up trial. After a one-week washout period, the participants performed the same resistance training protocol to create fatigue once again. The women, who had received CHO-PRO after the initial baseline trial, consumed CHO-ONLY post-exercise for this second baseline trial. Similarly, participants who had received CHO-ONLY the week before consumed CHO-PRO after their second baseline trial. Once again participants returned twenty-four hours later to perform the follow-up exercise trial for measurement of the effect of the recovery beverage on weight lifting repetition performance.

Overall muscle soreness produced by the CHO-PRO and the CHO-ONLY workout sessions was evaluated at the beginning of the follow-up session for each using a 100 mm visual analog scale where, 0 = little or no soreness and 100 = extreme muscle soreness.

The 10-RM weight load established in the pretest was the load used for each set of exercise in all four testing sessions. After arriving at the first weight machine, participants performed a warm-up set with approximately 60% of the 10-RM established for each exercise in the pre-test session. Before beginning the warm-up set or test trial, researchers reminded participants of the correct lifting technique. Afterwards, participants were reminded to lift until they felt momentary muscular failure. Momentary muscular failure was defined as the inability to perform a complete, non-assisted repetition. Supervisors gave no verbal encouragement or physical assistance in order to keep the testing environment as consistent as possible.

Investigators monitored and recorded the number of whole (full range of motion) repetitions that were performed. The participants performed three sets to momentary muscular failure of each exercise before moving to the next. Only the first set was used for statistical analysis to minimize error due to variability in rest periods between lift sets and interference between sets (e.g. a great first set may cause second set to be weaker). Therefore, the first set was assumed to be the most representative measure of performance. The second and third sets were performed to create fatigue associated with a full workout and create the stimulus for recovery with the different test beverages (CHO-PRO & CHO-ONLY) being investigated.

The number of successful repetitions accomplished by the participants during the first exercise session was the reference standard for the subsequent sessions. Recovery was defined by the ability to replicate or increase the mean number of repetitions performed during baseline in the first set of 8 exercises using for a 10-RM. After each set of each exercise and at the end of the testing session, the participant was asked to give a rating of the level of perceived exertion (RPE), (Borg 6-20 scale) (Borg, 1974) to determine set-by-set and overall subjective intensity. At the start of each follow-up exercise session, 24 h after the baseline workout, participants were asked to rate how prepared they were to complete the same volume of exercise from the previous day on a perceived recovery status (PRS) scale. The scale had the anchors 0 and 10 with 0 = to not recovered at all and 10 = fully recovered. Rating scales were attached to the investigator clipboard and visible to participants.

Participants were required to perform as many repetitions as possible for each set of each lift in four test sessions. These four sessions consisted of two baseline sessions (separated by one week) and two recovery sessions following 24 h of recovery after consumption of either CHO-PRO or CHO-only following the individual baseline sessions. The original order of exercises for the individual participant was held constant for each session. Participants exercised at the same time of day for the initial and subsequent sessions. The number of repetitions performed in each set for each exercise and the combined first set total for the session were recorded as previously outlined. PRS, RPE, and soreness ratings were recorded with the same instruments and in the same manner as mentioned previously. Participants completed a post-exercise lift and beverage evaluation after completion of each follow-up trial (CHO-PRO and CHO-ONLY).

Post-Exercise Nutritional Supplement

The two test beverages used in this study were a calorically sweetened, commercially available, whey protein exercise recovery drink (CHO-PRO) (Pro Performance 100% Whey Protein, General Nutrition Corporation, Pittsburgh, PA) which contained 40g of protein, 18g of carbohydrate, and 4g of fat, and an isocaloric carbohydrate placebo (CHO-ONLY) which contained 60g of carbohydrate and 2g of fat (Nesquik, Nestlé USA Inc. Glendale, CA). Participants consumed ~62 grams of the nutritional supplement dissolved in 400mL of water. All ingredients in the test beverages are found in commercial beverages of their kind and are approved as food additives by the United States Food and Drug Administration.

Beverage Administration

The beverages were chilled and served immediately after the cessation of exercise in clear plastic bottles. The beverages were similar in appearance and consistency. Both the investigators and the participants were blinded to the beverage contents. Blinding was achieved by having a research assistant who was not directly involved with data collection place the powdered form of each beverage into identical white containers marked "1" and "2". Neither the main investigator nor the data collection assistants knew the contents of container 1 or container 2 until after all data had been collected. The beverages were then given in counterbalanced order based solely on the numbered beverage the participant had received the prior week.

Statistical Analyses

All analyses were performed using SPSS for Windows statistical program (v. 18.0). A doubly repeated measures ANOVA was performed for the 4 lifting sessions to examine differences in mean repetitions. The GLM was followed by univariate analyses for all significant interaction and main effects. Bonferroni post-hoc contrasts were administered to detect which trends were significant for the recovery of each lift. Paired-sample t-tests were used to compare means for soreness and perceived exertion between the two follow-up exercise sessions only. Alpha levels were set at ≤ 0.05. Data were expressed as mean ± *SD.*

Results

Overall Lifting Performance

The change in mean repetitions performed since baseline for individuals and the group are illustrated in Figure 1 for CHO-PRO and CHO-ONLY, respectively. There was no significant trial x beverage interaction ($p = 0.73$) and no significant main effects for trial ($p = 0.21$) or beverage ($p = 0.73$) on the overall mean for repetitions performed. During the baseline CHO-PRO trial, participants performed 11.1 ± 1.1 reps versus 10.5 ± 1.6 reps during the 24 h recovery trial. The repetition mean for the CHO-ONLY trial was 11.7 ± 1.1 vs. 11.3 ± 2.0 in the 24 h recovery trial. Perceptions of effort were also similar between the two treatments (15.9 ± 1.1 vs. 15.8 ± 1.4, for CHO-PRO and CHO-ONLY, respectively; $p = 0.68$). This reported perception of effort would rate as "very hard" on the Borg scale.

Individual Lifting Performance

The individual mean (of eight lifts) data for the beverage trials were examined because an improvement by half the participants could be negated by a decline of similar magnitude in the other half of the participants. A participant was considered "adequately recovered" during the follow-up resistance exercise session if she could replicate or exceed the mean number of repetitions performed in the baseline session. This recovery session occurred 24 h after the baseline trial for each treatment. Three of the nine participants (33%) were able to replicate their baseline repetition mean during the recovery trial when the CHO-PRO supplement was consumed immediately post-exercise and five of the nine participants (56%) replicated their baseline numbers during the recovery exercise trial when using the CHO-ONLY beverage. Three of the nine participants (33%) who made a full recovery after consuming the CHO-ONLY supplement did not recover using the CHO-PRO supplement. Of the three participants who replicated their baseline performance with CHO-PRO only one did not show a full recovery when using the CHO-ONLY supplement also.

Soreness, Perceived Exertion, and Perceived Recovery

Group mean and individual ratings for overall body soreness are presented in Figure 2. Mean soreness for the treatments was not significantly different when using CHO-PRO or CHO-ONLY (33.6 ± 21.7 vs. 25.8 ± 15.9, $p = 0.24$). Mean soreness was also not different between body regions (upper vs. lower) across treatments (24.5 ± 18.9 vs. 27.8 ± 17.8, $p = 0.23$). Although not analyzed statistically due to small sample size, a noteworthy trend seen between the treatments was that a higher number (55% vs. 22%) of participants reported less overall body soreness when using the CHO-ONLY versus CHO-PRO, respectively. Participants who experienced less soreness when using the CHO-ONLY beverage reported a soreness rating that was ~48% lower than when they used CHO-PRO. Likewise, the two participants who experienced lower levels of soreness when using the CHO-PRO beverage also reported a ~48% lower soreness rating as well. Two remaining participants reported equal ratings of soreness.

Discussion

The main purpose of the present investigation was to determine if the addition of protein to a carbohydrate beverage, compared to a carbohydrate only beverage, could enhance 24 h muscle endurance recovery in well-trained females following an acute bout of strenuous resistance training. A secondary purpose was to examine the effect that supplementation has on indirect measures of recovery such as overall muscle soreness and perceived effort.

The findings of the current investigation do not support our hypothesis that a CHO-PRO beverage would enhance recovery in the 24 h period following intense resistance exercise. The main hypothesis was that CHO-PRO would allow our female participants to duplicate or exceed their baseline performance significantly better than a CHO-ONLY beverage. This was not the case as the mean difference in repetitions lifted following use of CHO-PRO (0.58 ± 1.2) was statistically similar ($p = 0.73$) to those performed with CHO-ONLY (0.43 ± 1.4).

Additionally it was proposed that muscle soreness following exercise while using CHO-PRO would be lower than with CHO-ONLY. However muscle soreness between the two was similar (33.6 ± 21.7 for CHO-PRO vs. 25.8 ± 15.9 for CHO-ONLY, $p = 0.24$). Lastly, RPE for CHO-PRO (15.9 ± 1.1) and CHO-ONLY (15.8 ± 1.4) did not statistically differ ($p = 0.681$).

These findings support Green et al. (2008), who measured changes in recovery following eccentric exercise and post-exercise consumption of a carbohydrate (CHO-ONLY, n = 6), carbohydrate-protein (CHO-PRO, n = 6), or non-caloric placebo (PLA, n = 6) and found similar strength losses across all three beverages. However, the female participants in the Green et al. (2008) study showed a 17% ± 2.3% performance deficit in maximal isometric quadriceps strength following 24 h of recovery and 11% ± 2.3% after 48 h of recovery across all three beverages. These significantly decreased levels of force production do not agree with our participant's non-significant losses (5% and 3%, $p > 0.05$) seen with CHO-PRO and CHO-ONLY supplementation trials in the current investigation. With the Green et al. (2008) investigation, participants performed six intervals x five minutes/interval of downhill running at eight mph with a 12% decline to induce fatigue and soreness. Two minutes of rest were given between intervals. However, recovery was measured via maximal voluntary isometric contractions of the quadriceps on an isokinetic dynamometer. In the current investigation, muscle endurance was measured in the same fashion that fatigue and soreness were created. This allowed for direct functional comparisons between baseline performance and follow-up performance occurring 24 h post-exercise. It is likely the differences in findings between the two investigations are the result of the mode of exercise and how the decrements in force production were measured in participants. Eccentrically biased exercise has been shown to produce force losses of a greater degree and longer duration compared to a typical dynamic contraction that oscillates between a concentric and eccentric phase due to larger absolute forces spread over fewer recruited motor units (Wojcik, Walber-Rankin, Smith, & Gwazdauskas, 2001).

The lack of an enhanced effect on recovery with the addition of protein to our carbohydrate beverage supported the findings of a recent investigation (Cockburn, Hayes, French, Stevenson, & St Clair Gibson, 2008; Miller, et al., 2003; Rasmussen, et al., 2000). Cockburn et al (2008) compared the effect of four different beverages on muscle strength and soreness 24 h and 48 h post exercise via isokinetic knee flexion. The four test beverages were a carbohydrate-protein beverage, a carbohydrate-only beverage, milk, and water. To create fatigue and soreness, participants unilaterally performed eccentric and concentric knee flexion at a speed of 1.05 $rad*s^{-1}$ for six sets of ten repetitions. Participants consumed 500 mL of the test beverage immediately post exercise and consumed another 500 mL two hours later. Similar to our findings, performance (peak torque) was not significantly different ($p > 0.05$) from baseline measurements 24 h post-exercise when the participants consumed the carbohydrate-protein beverage versus the carbohydrate only beverage. Additionally, there was no difference in soreness at any time point regardless of the beverage consumed. The results of the two investigations were similar despite a much larger calorie content of the CHO-PRO beverage used in the Cockburn et al. (2008) investigation (707 Kcals) compared to the present investigation (~250 Kcals). However, protein content was similar (40g vs. 33g of whey protein) between the two studies and thus any performance or soreness improvements related specifically to protein ingestion should be similar for both groups. These similar findings with a greater level of calories contributed by carbohydrates in Cockburn et al. (2008) may point to a ceiling effect of the resulting hyperinsulinemia seen with carbohydrate consumption and its promotion of an anabolic state. This anabolic state is necessary for protein synthesis and subsequent repairs to damaged muscle tissue to occur.

One of our limitations was our lack of absolute control over our participants. It is possible that the variability in previous training habits, session duration, frequency, and intensity among participants may account for some of the variability observed in this study. However, all participants were experienced because this was an *a priori* requirement for inclusion in the investigation. Also diet was not controlled among participants. Therefore the potential exists that some participants did not receive a similar quality of macronutrient intake following the strenuous protocol. Participants maintained a food log to demonstrate that caloric intake was similar for a given participant even if not comparable between participants.

Variations in sleep and activity patterns may have contributed to fluctuations in performance as well, since the pool consisted of college students with varying time demands over the course of the investigation. All participants were asked before beginning each test session whether they had received adequate rest and were to the best of their knowledge physically and mentally prepared to exercise with an all-out effort. All participants indicated for all sessions that they met these two criteria and acknowledged as such by initialing their original informed consent.

These variations are present in individuals performing resistance training in the context of a busy schedule. Therefore, although they may be viewed as limitations, they may also reflect an ecologically valid approach to monitoring recovery among recreational weight lifters. Comparisons to other research investigations must be considered in light of this.

Aside from the previously mentioned limitations and the absence of differences in group means between CHO-PRO and CHO-ONLY, there were practical differences in the individual results between the current investigation and previous research in our lab that may provide some useful comparisons. During a recent investigation by Campbell et al. (2010), utilizing an identical exercise protocol and the same participant group, only one of the participants recovered fully in the 24 h period following the baseline exercise session (although, on average, participants were fully recovered). Participants did not consume any post-exercise beverage. In the current investigation, five of those same participants recovered in 24 h after consuming the CHO-ONLY beverage and three with consumption of a CHO-PRO beverage. This finding is the most direct evidence that a post-exercise nutritional intervention may enhance recovery in young women when performing repeated, day-to-day bouts of strenuous resistance exercise, but CHO may be a more important nutrient than PRO, under the conditions of our study.

There was no difference between the ratings of perceived exertion ($p = 0.10$) or soreness ($p = 0.37$), when comparing the two drinks following 24 h of recovery. Therefore, the notion that muscle soreness delays the return of strength and increases the perception of exertion while performing a follow-up bout of exercise is not supported by the current findings.

Ultimately the addition of protein in the form of whey isolates has been shown to improve performance with chronic use before, during, and after resistance training (Rasmussen et al. 2000; Cribb et al. 2007; Hartman et al. 2007; Cockburn et al. 2008). Whey protein contains the essential amino acids necessary for regeneration of muscle cells damaged during strenuous lifting. It has been proposed that whey protein supplementation may promote an enhanced and quicker recovery (Esmarck et al., 2001; Kerksick et al., 2006; Hartman et al., 2007; Tipton et al., 2007; Wilkinson et al., 2007; Willoughby et al., 2007). When consumed immediately following resistance exercise, a combination of whey protein plus carbohydrate has been shown to increase protein synthesis to a greater extent than an isocaloric, carbohydrate-only placebo for a period of 1-3 hours post-exercise (Skillen et al., 2008; Ivy et al., 2002; Borsheim et al., 2004; Hoffman, 2007; Tipton et al., 1999; Fujita et al., 2009). Despite these findings in other research, the results of our investigation do not support the addition of whey protein to a post-exercise carbohydrate beverage for consumption following acute, resistance exercise for the purposes of enhanced recovery.

In conclusion, the results of the current investigation suggest that when calories are controlled, consumption of a CHO-PRO or CHO-ONLY beverage results in similar soreness and muscle endurance performance. The treatment means for soreness and performance did not differ significantly compared to baseline values following 24 h of recovery. Additionally, when compared to a previous investigation involving the same cohort and exercise protocol without a nutritional intervention, supplementation with CHO-PRO or CHO-ONLY appears to improve performance without an improvement in muscle soreness or perceptions in effort. The individual results suggest that, practically speaking, supplementation may be indicated for responsive individuals. This is evidenced by the fact that 56% and 33% of female exercisers using CHO-ONLY or CHO-PRO, respectively, matched or exceeded their baseline performance after only 24 hours recovery compared to 10% when no supplementation was utilized (Campbell 2010).

Future investigations are needed to assess the time course of improvements that may occur when recovery is observed beyond 24 hours. It may be that long-term PRO supplementation impacts muscle performance. Additionally, supplementation should be examined when administration occurs before, during, and after exercise to assess the timing and schema for possible improvements in recovery after resistance training.

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Tables

Table 1 – Mean (SD) participant demographics and training history (n=9).

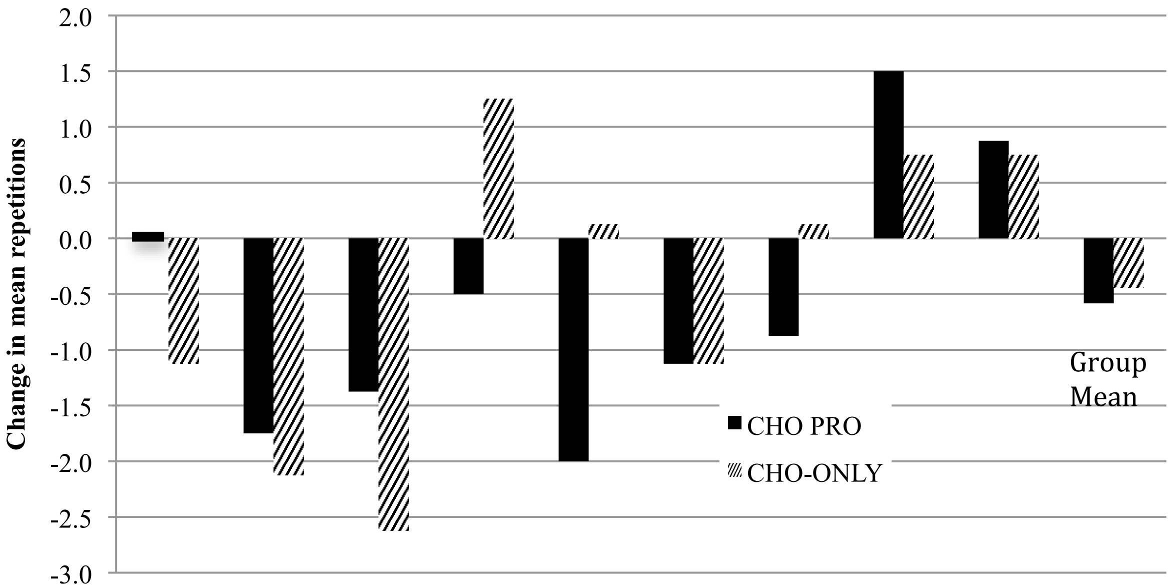
Demographics	
Age (years)	20.7 (1.2)
Height (cm)	164.3 (4.2)
Weight (kg)	58.7 (7.9)
Body fat (%)	22.0 (4.5)
Body Mass Index (kg/m^2)	21.9 (2.4)
Systolic Blood Pressure (mmHg)	98.3 (5.8)
Diastolic Blood Pressure (mmHg)	66.1 (4.1)
Training history	
Training (years)	2.7 (2.1)
Frequency (days/wk)	2.8 (1.3)
Sets per exercise	3.4 (0.9)
Reps per set	12 (1.9)
Length of typical workout	54.3 (15.4)

Table 2 – Mean (SD) for beverage and lift evaluation responses (n = 9). Scores are from a 100 mm visual analog scale.

Evaluation Questions	**CHO-PRO**	**CHO-only**
1. How difficult was today's workout compared to one of your normal workouts? (0 = less difficult 100 = more difficult)	60.1 (12.0)	54.2 (13.8)
2. Did you feel drinking this beverage after your last workout improved your performance ability? (0 = didn't improve 100 = did improve)	48.9 (17.0)	43.9 (31.9)
3. How was the taste of the beverage? (0 = didn't like the taste 100 = did like the taste)	60.0 (29.8)	74 (26.0)
4. How was the after-taste of the beverage? (0 = no after-taste 100 = heavy after-taste)	64.4 (33.1)	58.4 (35.3)
5. How did you feel about the amount of beverage you drank after the lift? (0 = too little 100 = too much)	59.8 (21.5)	58.3 (15.3)
6. Did you experience any stomach discomfort related to drinking the beverage after the lift? (0 = no discomfort 100 = bad discomfort)	24.8 (33.8)	31.1 (34.4)
7. How likely would you be to choose to drink this beverage **before** a workout? (0 = very unlikely 100 = very likely)	35.2 (34.2)	26.9 (23.7)
8. How likely would you be to choose to drink this beverage **after** a workout? (0 = very unlikely 100 = very likely)	68.9 (26.3)	62.0 (35.1)

Figures

1.


2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
Change in mean repetitions
Group Mean
CHO PRO
CHO-ONLY

2.

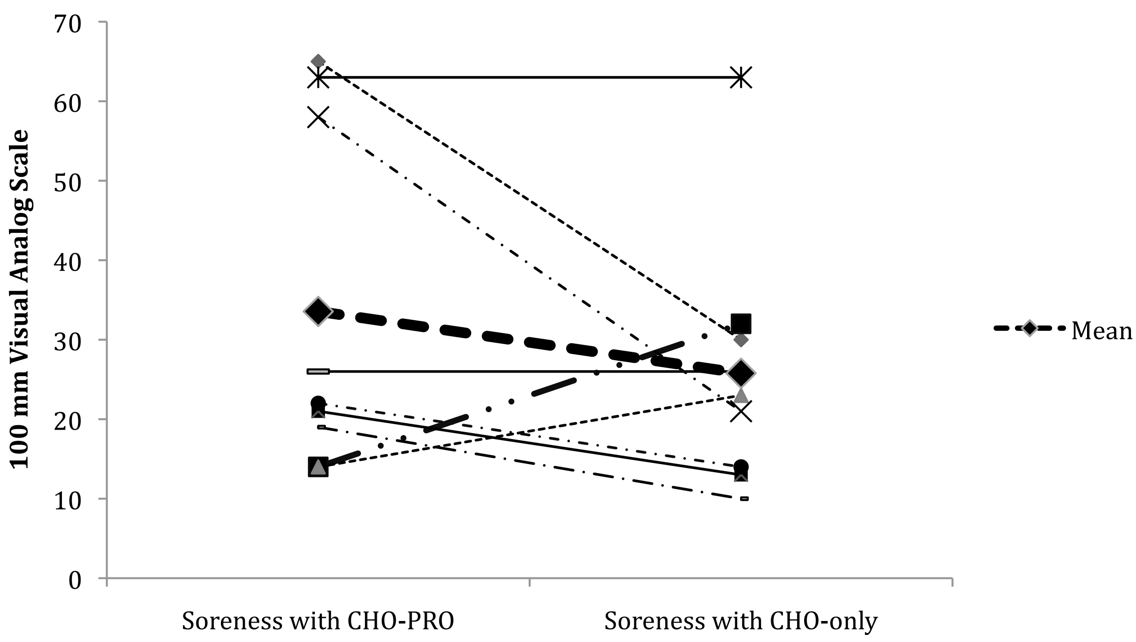

70
60
50
40
30
20
10
0
100 mm Visual Analog Scale
Mean
Soreness with CHO-PRO
Soreness with CHO-only

Figure Captions

Figure 1. – Change in mean repetitions (8 exercises) for individual and group compared to baseline after consuming CHO-PRO or CHO-ONLY (n = 9). Group mean difference was not significant (p>.05)

Figure 2. – Group mean and individual ratings for overall body soreness (n = 9). Group mean difference was not significant (p>.05)

CHAPTER IV

VALIDATION OF A PERCEIVED RECOVERY SCALE WITH TRAINED FEMALES PERFORMING EXHAUSTIVE RESISTANCE TRAINING

Abstract

The current investigation examined the efficacy of a previously developed perceived recovery status (PRS) scale following intense resistance training. Following completion of a baseline trial, 10 healthy, resistance-trained female participants, were given variable counterbalanced recovery periods of 24, 48, or 72 hours at which point they repeated an identical weight lifting trial. The sensitivity and specificity of the scale were assessed by determining agreement between an individual's PRS recorded prior to the trial relative to their subsequent lifting performance (mean and total repetitions). The PRS demonstrated an overall sensitivity of 20% for mean repetition change (eight exercises combined) and 18% for change in total repetitions across three sets between trials. Overall specificity equaled 100% for mean repetition change (all eight exercises combined) and 95% for total repetition change when predicting the change in performance for resistance exercise compared to baseline. The ability of the PRS scale to accurately characterize the recovery status of a participant was independent of other markers measured during testing, as there were no differences among ratings of soreness or session ratings of perceived exertion (RPE) between trials. Results indicate that a subjective approach may be effective for assessing recovery.

Key Words: RPE, fatigue, practical performance testing, weight training

Introduction

Fatigue has been defined as a response that is less than the anticipated contractile response for a given stimulation (MacIntosh & Rassier, 2002). Many direct and indirect methods have been used to assess fatigue such as change in maximal voluntary force generation, power output, electrical stimulation, muscle twitch interpolation, endurance time, and electromyography (Vollestad, 1997).

Whereas fatigue can be thought of as a decrement in performance, recovery can be defined as the ability to meet or exceed performance in a particular activity (Bishop, et al., 2008). Ensuring the optimal recovery between exercise or training sessions should be considered an integral component to any training regimen (Bishop, et al., 2008; Coutts, Slattery, & Wallace, 2007; Jones, et al., 2006; Lambert, 2006; Lane & Wenger, 2004; McLester, et al., 2003).

Generally, two methods have been employed to evaluate recovery. The first is the use of an exhaustive exercise protocol, followed by a designated recovery period, and then an attempt to replicate the performance achieved during the baseline trial of that same exercise protocol (Gomez, et al., 2002; Jones, et al., 2006; Lane & Wenger, 2004; McLester, et al., 2003; Sayers & Clarkson, 2001). The second is the direct measure of by-products or physiological markers associated with overtraining (as the result of under-recovery) (Coutts, et al., 2007; Gomez, et al., 2002; Linnamo, et al., 1998). Both approaches have their own merit but unfortunately the latter method may be too involved or too technical for use with athletes on a day-to-day basis by coaches or trainers. Additionally, according to Hooper et al. (1995), it can be difficult to discern between adaptation and maladaptation. During heavy training, a decrease in performance is often expected prior to supercompensation. Supercompensation is the process of breakdown (training) followed by an overshoot adaptation resulting in improved performance ability following adequate rest (recovery). Often it is only possible to determine if a program created a positive adaptation *after* the program concludes (Kentta & Hassmen 1998). Therefore, the development and validation of easy-to-use and understand psychobiological tools for assessing the perception of recovery *during* training could prove beneficial. A subjective estimation of recovery *between* training sessions may be as applicable as monitoring sense of effort using ratings of perceived exertion (RPE) *during* training (Kentta & Hassmen, 1998). RPE has been shown in several investigations to be closely related to several physiological criteria used to determine exercise intensity (Green, et al., 2005, 2006, 2007). It is thought by some researchers (Nederhof, Lemmink, Visscher, Meeusen, & Mulder, 2006; Urhausen & Kindermann, 2002) that the same relationship may exist between a person's psychological perception of recovery and their true physiological recovery status.

In a previous investigation in our laboratory, recovery was observed following repeated 30-meter sprints in eight men and eight women who were at least moderately active (Laurent et al. 2009). To measure the psycho-physiological level of recovery following exhaustive exercise and following varying recovery durations, the researchers created and assessed the efficacy of a perceived recovery status (PRS) scale. The PRS is a 0-10, scalar representation of varying levels of an individual's perceived recovery status similar to that of the OMNI ratings of the perceived exertion (RPE) scale (Laurent et al. 2009). The main purpose of developing this scale was to provide an easy-to-use and familiar subjective measurement tool that could be used in the field in place of more invasive and complex quantitative measures.

In the Laurent et al. (2009) investigation, a stable relationship was found between the ability to perform repeated sprints over varying recovery periods and the subjective rating of recovery provided by participants on the PRS with a sensitivity and specificity of 82% and 81%, respectively. Further validation of this instrument across genders and different forms of training is warranted. Consequently, the aim of the present investigation was to evaluate the PRS when used to measure subjective recovery in resistance trained females in response to performing an exhaustive weight training protocol.

Methods

Overview

In this investigation, the validity of the perceived recovery scale was evaluated concurrently with another research study investigating recovery after varying durations (24, 48, or 72 hours) following an exhaustive resistance training protocol (see Campbell et al., 2010) for details of the exercise protocol. In brief, ten resistance-trained female participants performed a baseline workout involving three sets of eight exercises at the 10-repetition maximum (10-RM). The participants then returned 24, 48, or 72 hours, in counterbalanced fashion, and attempted to replicate or exceed the number of repetitions performed in the baseline session. Complete recovery was defined as the ability to duplicate the mean number of repetitions (across eight exercises) and total repetitions across three sets of the 10RM.

The Perceived Recovery Scale (PRS; Figure 1) was used to evaluate subjective recovery after each recovery duration.   The participants indicated on a scale from 0 to 10 (0 = very poorly recovered, 10 = very well recovered), how recovered from the previous exercise session they felt. This score was later compared to mean repetitions (eight exercises combined) and total repetitions across three sets of all eight exercise combined, as the main outcome variables to analyze the sensitivity and specificity of the PRS scale. Muscle soreness was also measured and compared to the PRS values in this investigation to detect if these factors were independent of each other. An initial baseline test session was used to create fatigue and soreness. Ratings of perceived exertion (RPE) were recorded following each set for all eight exercises and at the end of the weight lifting trial (session RPE).

Participants and Recruitment

Healthy women (n = 10) ages 19-35, who self-reported regular participation in resistance exercise (at least three times per week/all major muscle groups) over the last 2 months, with the exception of competitive lifters, were recruited for this study. Participant characteristics are shown in Table 1.

Familiarization and Pre-Testing

All participants completed a physical activity readiness questionnaire (PAR-Q), a medical history questionnaire, and a blood pressure screening to help ensure they were low risk for exercise according to American College of Sports Medicine (ACSM) risk stratification guidelines (2010). Height and body weight were measured on a stadiometer and beam-balance scale (Detecto, Webb City, MO). Body mass index was calculated from these measures. A 3-site (tricep/mid-thigh/suprailiac) skinfold measurement (Lange Caliper, Beta Technology Inc., Deer Park, NY) was taken in accordance with ACSM guidelines (2010) to estimate body fat percentage (Jackson and Pollock, 1985), which permitted estimation of fat free mass.

Only women with a regular menstrual cycle and who were on a monophasic birth control prescription were included in the participant pool. This requirement was added to control for hormone variations among subjects. Participants were instructed not to participate in any other resistance training activities besides the testing protocol during the duration of the study and were also instructed to maintain dietary habits as close as possible to those before the study. During the pretest session, participants also completed a questionnaire outlining previous and present exercise experience to assure the sample was experienced enough to qualify as required for inclusion in the study. Written informed consent, in accordance with the procedures for the protection of human subjects set forth by the local Institutional Review Board, was obtained before testing.

During session I, participants performed a 10-RM for eight different weight lifting exercises covering most major body parts. The eight lifts and accompanying muscle groups affected were as follows: seated upright bench press – pectoralis major, seated upright shoulder press – deltoids, seated elbow extension (triceps press) – triceps brachii, seated elbow flexion (biceps curl) – biceps brachii, seated arm pull-down (lat pull down) – latissimus dorsi, supine hip extension (leg press) – gluteus maximus and quadriceps, prone knee flexion (leg curl) – hamstrings, and seated knee extension (leg extension) – quadriceps.

As we have done previously (Campbell et al., 2010), each exercise was demonstrated with proper technique to help promote safe performance of each lift. In preparation for determining the 10-RM, subjects warmed up for each exercise with a light load that would easily allow ~15 repetitions. To determine the 10-RM, subjects lifted a self-selected initial weight and resistance was increased by 2.8 to 5.7 kg (depending on difficulty) for each of the lifts until approximately a 10-repetition max was elicited (9-11 RM acceptable). Two to four minutes of rest were provided between trials to allow for adequate recovery. All l0RM tests were supervised by the same experienced technician to make sure the 10-RM was found within three trials and that the testing was consistent across subjects. If the participant failed to obtain the 10-RM within the first three attempts, the participant went on to the next exercise, and returned to the original exercise at the end of the test session for another three attempts. If unsuccessful on this follow up attempt, the participant was asked to return one week later to allow for dissipation of any soreness and to repeat the 10-RM process. Once found, this 10-RM weight was used for all training sessions that followed. Each subject was then randomized to a counterbalanced treatment sequence. Participants were given detailed verbal and written instructions on pre-trial nutritional intake as well as provided a food log to record daily food consumption. The aim of this procedure was to keep daily nutritional intake as similar in content and portion size as possible throughout the 10-day testing period. If a participant showed a 20% change (calculated on www.mypyramid.gov) in caloric intake compared to their baseline session, their training session was re-scheduled.

Procedures for Exercise Training Sessions

Participants were instructed to avoid consuming food or beverages, other than water, two hours prior to testing, caffeine for four hours prior to testing, and alcoholic beverages 24 hours prior to testing. Participants returned 24, 48, or 72 hours after the baseline workout to perform subsequent sessions with the recovery time between trials assigned to participants randomly but in counterbalanced order. Counterbalancing was used to partially offset any training effects that might accrue from any particular timing of resistance training sessions. Participants completed each of the three different sessions at the same time of day as their baseline.

An initial baseline test session was used to elicit fatigue and soreness. Muscle soreness produced by the previous workout session was evaluated using a 100-mm visual analog scale where, 0 = little or no soreness and 100 = extreme muscle soreness. These trials began at least three days after the predicted end of the participant's last day of menses and ended at least three days prior to the predicted beginning of menses. Sessions were conducted over a strict 10-day schedule due to the specific recovery duration requirements.

As in our previous studies (Campbell et al., 2010) the 10-RM weight load established in the pretest was the load used for each set of exercise in all four testing sessions. The exercises (mentioned previously) were performed using Cybex machines (Lumax, Ronkonkoma, NY). After arriving at the first weight machine, participants performed a warm-up set with approximately 60% of the 10-RM established for each exercise during the pre-test session. Before beginning the warm-up set or test trial, researchers reminded participants of the correct lifting technique. Afterwards, participants were reminded to lift until they felt momentary muscular failure. Momentary muscular failure was defined as the inability to perform a complete, non-assisted repetition. However, supervisors gave no verbal encouragement or physical assistance in order to keep the testing environment as consistent as possible. Investigators monitored and recorded the number of whole (full range of motion) repetitions that were performed. The subjects performed three sets to momentary muscular failure of each exercise before moving to the next exercise. Sets and exercises were separated by a one-minute rest period.

The mean number of repetitions for the first set and the total number of repetitions performed in set one, two, and three combined for all eight exercises by the participant during the first exercise session was the reference standard for the subsequent sessions. After each set of each exercise and at the end of the workout session, the participant was asked to give a rating of the level of perceived exertion (RPE), (Borg 6-20 scale) (Borg, 1974) to determine set-by-set and session subjective intensity. All rating scales were attached to the reverse side of the investigator's clipboard and visible to the participants. A stopwatch was used to time and standardize the rest interval between sets at one minute for all participants. This procedure was used to help ensure participants all had a uniform acute recovery break to standardize work intensity.

Participants were required to perform as many repetitions as possible for each set of each lift in the test sessions that followed (24, 48, and 72 hours after the previous session, counterbalanced among subjects). The original randomly established order of the eight exercises for each individual during the initial session was held constant for all subsequent sessions. Participants exercised at the same time of day for all sessions.

Statistical Analyses

The key statistics assessed to provide evidence for validity were the sensitivity, specificity, positive predictive value, and negative predictive value of the PRS scale. These four measures were used to evaluate the classification and prediction ability of the PRS scale related to our measure of recovery. The calculation of these measures was based on the number of true positives, true negatives, false positives, and false negatives reported by participants. A true positive (PRS < five) indicated the presence of fatigue (reduced lifting performance), whereas a true negative (PRS ≥ five) indicated the absence of fatigue (replicated or improved lifting performance). A false positive indicated that the participant responded as if she were not recovered (fatigue; PRS score < five) but actually performed better than baseline. Lastly, a false negative indicated that the participant responded with a PRS score ≥ five, but had a compromised lifting performance.

Sensitivity was calculated as the proportion of true positives to true positives plus false negatives while specificity was calculated as the proportion of true negatives to true negatives plus false positives. Additionally, the positive predictive value was calculated as the proportion of true positives to true positives plus false positives. Lastly, the negative predictive value was calculated as the proportion of true negatives to true negatives plus false negatives.

These statistical measures were calculated using three markers of recovery recorded during each exercise session. The first marker of recovery was the participants' perceived recovery status as assessed by the PRS estimation (recorded prior to beginning each trial). The criterion marker of recovery was computed as the difference between mean number of repetitions (eight exercises combined) performed in the first set during the baseline trial compared to the mean repetitions performed in the first set of each subsequent bout of exercise following 24 h ($\Delta Reps_{24}$), 48 h ($\Delta Reps_{48}$), and 72 h ($\Delta Reps_{72}$) of recovery, respectively. Finally, the overall criterion recovery measurement was the total number of repetitions performed in all three sets combined for the eight resistance exercises.

Lifting performance, soreness, RPE, and PRS were analyzed using repeated measures ANOVA with post-hoc analyses including Bonferroni adjustments, when appropriate to identify the effect of the specific recovery times on outcome measures (reported previously in Campbell et al., 2010). All data were analyzed using SPSS (v. 18.0) and are reported as mean ± SD. Statistical significance was set *a priori* at an alpha level of 0.05.

Results

The descriptive characteristics of the participants are shown in Table 1. Table 2 details each individual's mean repetitions performed during the baseline trial ($REPS_0$) and the difference in mean repetitions ($\Delta REPS$) during each subsequent trial ($REPS_{24}$, $REPS_{48}$, $REPS_{72}$) as well as their respective PRS value (PRS_{24}, PRS_{48} and PRS_{72}) reported prior to performing each respective trial. The PRS scores and lifting performances are shown in Table 3.

There were no group differences ($p > 0.05$) for mean repetition change compared to baseline for any recovery period and soreness was significantly higher ($p > 0.05$) than baseline at all time points. Additionally, session RPE was not significantly different ($p > 0.05$) between recovery periods.

Individual differences existed however in the rate of recovery. Only 10% of individuals reproduced their baseline lifting performance at 24 h post-exercise. At the same time point, the PRS scale positive prediction value was 100% (two true positives, zero false positives) and the negative prediction value was 14% (one true negative, seven false negatives) based on the performance outcomes. The PRS positive prediction value equaled 100% (one true positive, zero false positives) while the negative prediction value improved to 78% (seven true negatives, two false negatives) at 48 h, and showed 70% negative prediction value (seven true negatives, three false negatives) after 72 h of recovery. Positive prediction value could not be calculated for 72 h of recovery since no true positives or false positives were observed from participants.

Overall sensitivity for the change in mean repetitions compared to baseline for all recovery periods combined (24 h, 48 h, and 72 h) was 20% and the overall specificity was 100%. No false positives were present at any time point, which indicated that when a participant responded with a PRS < five, they also demonstrated a concurrent decrease in performance. Additionally, no participants reported a PRS score < five beyond 48 h of recovery; likewise, beyond 48 hours there was no participant with evidence of being under-recovered. For total repetitions performed across all three sets and for (eight exercises and all recovery periods combined), the sensitivity was 18% and the specificity was 95%. The sensitivity of the PRS scale was 20% for the upper-body exercises and 8% for the lower body, while specificity was 95% for upper-body exercises combined and 89% for all lower-body exercises combined.

For the 24 h, 48 h, and 72 h recovery periods, sensitivity when considering the mean change in repetitions for the first set was 22%, 33%, and 0%, respectively (at 72 h all participants were fully recovered). For the same recovery periods, specificity of the PRS scale was 100% at all time points. When looking at total repetitions performed over three sets, sensitivity at 24 h, 48 h, and 72 h post-exercise was 17%, 50%, and 0%, respectively. One false positive (PRS < five, but improved performance) occurred at both 24 h and 48 h post-exercise where one participant indicated a PRS of four with an improvement in repetitions. It was expected that the PRS would demonstrate a sensitivity of zero at 72 h post-exercise, since at that point all subjects were recovered (absence of fatigue) and therefore, no true or false positives would be indicated. However, three participants responded with false negatives, due to the participants indicating a PRS score ≥ five with a lifting performance worse than baseline. The specificity for the same time periods with respect to the same totals was 75% at 24 h and 100% for both 48 h and 72 h of recovery.

Discussion

A well-developed training plan addresses both the necessary stimulus for breakdown, as well as, the rest required for adaptation subsequent to increased demands. Although both elements should be considered of equal importance, the bulk of research surrounding the desired supercompensation has focused on the fatigue stimulus rather than recovery from training (Bishop, et al., 2008). Monitoring the status of recovery to help ensure the absence of fatigue prior to beginning another training session is essential for avoiding the overtraining syndrome (Sayers & Clarkson, 2001). In order to assess recovery regularly it would seem that the development of non-invasive evaluation tools would be of value (Kentta & Hassmen, 1998). Therefore the aim of the present investigation was to assess the validity of using a subjective recovery scale (PRS) with trained females following intense resistance training prior to a subsequent exercise bout.

The findings of the current study demonstrate a high level of specificity (≥ 95% overall) associated with the use of the PRS scale to measure recovery from intense resistance training in females. Specificity indicates the ability of an instrument to correctly classify participants as being absent of fatigue. Overall specificity (24 h, 48 h, 72 h recovery responses combined) was highly related to both the change in mean repetitions for the first set (100%), as well as, for the complete workout over three sets (~95%). These findings are in agreement with Kellman et al (2000) who examined subjective recovery patterns in elite rowers and observed a significantly better ($p < 0.05$) race performance in rowers who indicated the lowest levels of stress and highest ratings for recovery compared to their teammates. In the current investigation sensitivity was defined as the ability of the PRS to identify participants who were suffering from fatigue as indicated by the inability to replicate their baseline performance. Overall sensitivity (24 h, 48 h, 72 h recovery responses combined) of the PRS scale was 20% and 18% for the change in mean repetitions and total repetitions, respectively.

Based on the rarity of under-recovery in our sample, the scores indicated by participants on the PRS scale were rarely in agreement with their actual lifting performance, except when the participants indicated a PRS < five (under-recovered). In contrast, Laurent et al., (2009) found an overall sensitivity of 82% compared to 20% for mean repetition change from baseline in the first set and 18% sensitivity when considering the change in total repetitions performed in set one, two, and three combined. This lack of sensitivity in the current investigation may indicate that only in some of the most extreme cases of fatigue will participants actually score themselves as fatigued. This statement is supported by the inability for nine of ten individuals to match their baseline performance despite indicating on the PRS scale that they felt they could. In our sample, the participants were overly optimistic regarding their abilities.

The negative predictive value of the PRS scale (Table 3) was defined as the ability of the scale to accurately classify recovered participants as recovered when the PRS score was ≥ five compared to the total number of responses given that were ≥ five. Positive predictive value was defined as the ability of the scale to accurately classify fatigued participants as fatigued when the PRS score < five compared to all responses that were < five. There was a tendency to be more accurate when the PRS score fell below five as compared to when the participants submitted a score greater than five. During the first two recovery periods (24 h and 48 h), there were only three times where participants reported a PRS below five and at no point did any of participants respond similarly following 72 h of rest. In these three instances all of the participants experienced a decrement in their lifting performance demonstrating 100% accuracy at PRS scores below five. The PRS scale was only accurate for scores above five, 62.5% of the time when predicting improved or replicated performance. This inability to predict when an athlete may under-perform better than random chance (50-50 chance at predicting accurately) does not provide evidence that the PRS could identify those who were mistakenly perceiving themselves as adequately rested, when in fact they were under-recovered. To that end, 37.5% of the time when our participants indicated that they felt capable of replicating or exceeding their baseline performance, they actually fell below, thus indicating a "false negative", i.e. they thought they were without fatigue, but fatigue was still present.

Beyond 48 h, no one indicated that a deficit would be present (everyone reported a five or higher) and there were no instances of under-recovery by our measure. It is logical that participants experiencing the extremes of either fatigue (extremely under-recovered) or recovery may be more likely to recognize and indicate their expectation of a deficit or improvement in performance more than those participants who are close to a full recovery or who are merely recovered enough to replicate performance. Although it would be valuable for the PRS scale to make accurate predictions along the entire spectrum of the scale, the ability of a diagnostic tool to accurately identify those who are at the greatest risk for or are beginning to experience the overtraining syndrome is a main concern. Ultimately, the findings that when participants rated their perceived recovery to be < five, the positive predictive value was 100%, may illustrate that fatigue at extreme levels will manifest strongly enough to be detected by such a tool.

In the present investigation, at no point did any participant report a score on the PRS scale below four. This result may suggest that the exercise protocol was not intense enough to elicit a proper stratification across responses, which is essential for validation at all points on the PRS. It is important to remember that although the group mean for performance was not significantly decreased, only one individual was fully recovered after 24 h of rest. At 48 h of recovery, two participants remained fatigued as shown by their inability to replicate their baseline performance.

When considering the overall specificity and sensitivity of the PRS scale it is important to note that the previous scenario resulted from no false positives being reported at any time point. This means that none of the participants under-estimated their ability to match or improve their performance by stipulating they were "fatigued", when in actuality they were fully recovered.

With a specificity of 100%, the findings indicated that when looking at mean repetitions only from the first set of exercise regardless of the amount of recovery, the PRS has good agreement with performance, as evidenced by the fact that when people indicated they weren't fatigued, the number or repetitions performed were at, or exceeded, baseline.

It would seem most desirable for the PRS scale to have a high level of sensitivity versus specificity. Ultimately, practitioners are more concerned with those athletes that are at the threshold of overtraining. The hope is to detect their under-recovered status so that their training plan can be altered to provide enough rest to reverse the fatigue created by exercise. If this increase in sensitivity results in a few athletes being misclassified as "false positive", meaning they indicate the presence of fatigue but are truly rested, then the resultant outcome would be that the coach or trainer allowed some athletes a bit of additional rest that could serve them positively in the long run. Importantly, the increased sensitivity would help ensure that fewer truly fatigued participants would be thrust back into an intense training plan prematurely.

In conclusion, the findings of this investigation may provide support for the notion that subjective recovery responses consider not only the participant's psychological state (i.e., feeling fatigued, lack of energy, etc.) but also consider the current metabolic and physiologic state prior to beginning the training session (Coutts et al. 2007; Kentta and Hassmen 1998). The PRS scale was able to specify those participants that were recovered when reporting PRS values greater than or equal to five. Additionally, the PRS was sensitive to under-recovered participants in the first 48 h post-exercise who reported subjective scores below five, but showed poor sensitivity when participants reported PRS scores equal to or greater than five. The results of the present investigation may offer some utility for accurate monitoring of day-to-day recovery status related to performance potential during repeated weight training sessions using the PRS scale. Future work regarding the utility of the PRS scale in the prevention and/or diagnosis of overtraining is undoubtedly needed. Additionally, a longer monitoring period with both trained and untrained participants may shed some additional light on the efficacy of using a subjective monitoring system to guide the training plan. It would also be beneficial to examine responses between genders and across age to compare if there are differences in the perception of fatigue and how this fatigue may manifest itself concurrently, both psychologically and physiologically. The PRS scale may ultimately benefit from a broadened spectrum of subjective recovery responses similar to the RPE scale, as indicated by Kentta and Hassmen (1998).

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Tables

Table 1 – Mean (SD) participant demographics and training history (n=10).

Demographics	
Age (years)	21.1 (1.4)
Height (cm)	163.1 (4.6)
Weight (kg)	58.1 (8.7)
Body fat (%)	21.9 (4.9)
Body Mass Index (kg/m^2)	21.7 (2.6)
Systolic Blood Pressure (beats/min)	98.4 (5.7)
Diastolic Blood Pressure (beats/min)	66.4 (3.7)
Training history	
Training (years)	3.3 (2.8)
Frequency (days/wk)	3.2 (0.6)
Sets per exercise	2.8 (0.6)
Reps per set	12.0 (2.3)
Length of typical workout (min)	56.7 (16.0)

Table 2 – Mean repetitions performed (for eight exercises combined) and total repetitions (set 1,2,3 for eight exercises combined) during the baseline trial and the difference in mean repetitions (ΔREPS) and PRS scores during each subsequent trial (24, 48, 72 h) following each recovery period for each individual (n = 10)

$REPS_0$	**TOT_0**	**PRS_{24}**	**$\Delta REPS_{24}$**	**ΔTOT_{24}**	**PRS_{48}**	**$\Delta REPS_{48}$**	**ΔTOT_{48}**	**PRS_{72}**	**ΔREPS72**	**ΔTOT_{72}**
10.4	201	6	-0.8	8	**7 †**	0.6	26	**9 †**	0.8	36
10.8	206	**4 †**	-0.1	11	**6 †**	0.8	24	**8 †**	1.1	41
9.6	212	6	-2.1	-43	**4 †**	-0.3	-15	9	-0.5	-29
10.3	188	**4 †**	-0.5	-14	**8 †**	1.0	3	**8 †**	2.8	29
10.5	198	6	-0.5	-10	**9 †**	2.8	53	**8 †**	1.3	22
11.0	224	**6 †**	0.0	5	**5 †**	1.1	7	**6 †**	1.4	9
10.8	210	5	-0.3	7	7	-0.3	-15	**9 †**	0.8	13
11.0	210	5	-0.1	-5	**6 †**	0.9	6	**9 †**	1.4	2
10.6	192	6	-1.6	-27	7	-0.6	4	7	-0.9	-11
11.5	224	6	-0.1	-11	**7 †**	2.1	23	**7 †**	0.1	-1

$REPS_0$, mean repetitions during the first trial; TOT_0, total repetitions of set one, two, three combined during the baseline trial; $\Delta REPS_{24}$, change in mean repetitions between the first trial and second trial; ΔTOT_{24}, change in total repetitions between first trial and second trial; PRS_{24}, perceived recovery scale score of recorded immediately prior to the second trial; $\Delta REPS_{48}$, change in mean repetitions between the second trial and third trial; ΔTOT_{48}, change in total repetitions between trial two and trial three; PRS_{48}, perceived recovery scale score of recorded immediately prior to the third trial; $\Delta REPS_{72}$, change in mean repetitions between the third trial and fourth trial; ΔTOT_{72}, change in total repetitions between trial three and trial four; PRS_{72}, perceived recovery scale score recorded immediately prior to the fourth trial

† Indicates an accurate assessment of recovery relative to change in mean repetition performance (either improved or declined) from the previous bout

Table 3 – The negative and positive predictive values of PRS scores (PRS > five = recovered, < five = fatigued) given by individuals relative to their change in mean repetitions across all trials (n = 10).

	N	Number of subjects who increased or replicated the repetitions performance relative to baseline	Number of subjects who decreased the number of repetitions performed relative to baseline
PRS > 5 (no fatigue)	24	15	9
		Negative Predictive Value	
%		62.5%	37.5%
PRS < 5 (fatigue)	3	0	3*
			Positive Predictive Value
%		0.0%	100.0%

PRS, perceived recovery status
*Considered an accurate estimate of recovery status relative to change in mean repetitions

Figures

Perceived Recovery Status Scale

10	Very well recovered / Highly energetic	Expect Improved Performance
9		
8	Well recovered / Somewhat energetic	
7		
6	Moderately recovered	Expect Similar Performance
5	Adequately recovered	
4	Somewhat recovered	
3		
2	Not well recovered / Somewhat tired	Expect Declined Performance
1		
0	Very poorly recovered / Extremely tired	

Fig. 1 The Perceived Recovery Status (PRS) scale

CHAPTER V

CONCLUSIONS

Conclusions from these studies imply that women, as a group, were able to recover sufficiently and replicate their baseline performance 24 h after a bout of intense, all-body resistance exercise. This time period was of particular interest, since many collegiate athletes must do exhaustive workouts on consecutive days, and without adequate rest, and may become overtrained, stale, or injured. Additionally, there was no difference in perceptions of effort across recovery periods of varying length despite significant muscle soreness. This finding suggests that perceptions of pain may not be a sufficient indicator for establishing when an athlete is recovered prior to beginning a subsequent training bout.

There was no difference in group performance (mean repetitions, eight exercises combined), RPE, or muscle soreness consequent to 24 h of recovery with consumption of either a CHO-PRO or CHO-ONLY beverage compared to recovery without a beverage. However, the number of participants who were able to recover in this time period went from 10% with no beverage, to 56% when using CHO-PRO and 33% with CHO-ONLY. More work is needed where supplementation occurs over a longer duration to understand what advantages, if any, exist for the use of these supplements following intense resistance training in females.

Finally, perceptions of recovery, as measured on a perceived recovery status (PRS) scale, may not be sensitive enough to distinguish between recovered and under-recovered athletes except when the participant indicates a PRS score < five. Accuracy of the PRS may be improved if administered following a brief warm-up prior to the actual start of intense training, so that athletes can incorporate overall assessments of fatigue and soreness instead of simply assessing their perceptions following a period of passive rest.