THE EFFICACY OF SUBJECTIVE AND OBJECTIVE INDICES OF RECOVERY DURING AND FOLLOWING EXHAUSTIVE RESISTANCE EXERCISE

by

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ABSTRACT

Monitoring recovery status within and between exercise sessions can optimize training adaptations. As such, it is critical that the tools we use to monitor recovery status are both valid and reliable. One such tool, perceptual recovery status (PRS), has been developed to assess recovery status between days of repeated sprinting exercise. Yet, few studies have investigated the validity of PRS as a marker of recovery between sets or days of resistance exercise, or how fatigue influences the stability of performance indices. We conducted three studies to address these gaps. Study 1 investigated the utility of PRS as a marker of daily recovery following a bout of resistance exercise. Performance tests and PRS were recorded as baseline, 24, 48, and 72 h following a fatiguing high-volume back squatting protocol. Strong correlations were revealed between PRS and countermovement jump, bar velocity, isokinetic knee extension, and isometric mid-thigh pull (r = .61 to .86; $p < .001$). Study 2 evaluated the validity of PRS as a marker of inter-set recovery using bar velocity metrics during a high-volume back squatting protocol. Peak and mean bar velocity, as well as their decrements within a set were calculated across 4 sets of back squat. Main effects for time were observed for PRS and mean bar velocity metrics ($p < .05$) where all metrics tended to decrease throughout the bout. Strong correlations were observed between PRS all bar velocity metrics (r = .55-.65; $p \leq .001$). Study 3 investigated the influence of fatigue on the stability of performance indices following a single bout of resistance exercise. Daily recovery scores—calculated from performance tests recorded at baseline and again at 24, 48, and 72 h post-fatiguing protocol—were used to represent four different fatigue states (FS). Reliability analyses for each performance test revealed that intraclass-correlation coefficients

(ICC) remained high (ICC > .79) and standard error of the measurement values were comparable regardless of an individual's FS. Therefore, PRS can be used as a subjective metric of recovery between sets and days of exercise and FS does not affect the stability of objective performance metrics.

DEDICATION

This dissertation is dedicated to my parents. This project was the product of the work ethic you instilled in me, the encouragement you have always given me, and the lessons you have taught me. None of this would have been possible without your love and support and I will never forget that.

LIST OF ABBREVIATIONS AND SYMBOLS

1RM	one-repetition maximum
BMI	body mass index
Cl	confidence interval
cm	centimeter
FS	fatigue state
ES	effect size
h	hour
ICC	intraclass correlation coefficient
kg	kilogram
M	mean
m	meter
MD	minimal difference
min	minute
MS_S	Mean square subjects
MS_E	Mean square error
PRS	perceptual recovery status
s	second
SD	standard deviation
SEM	standard error of the measure
y	year

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CHAPTER 1

INTRODUCTION

The goal of any resistance training program is to optimize performance through careful consideration of both the stress applied to an individual and the time allotted to recover from that particular stressor. Acutely, under-recovery between sets of exercise may not negatively impact performance per se, it can, however, result in suboptimal chronic adaptations to training (Schoenfeld et al., 2016). Indeed, a chronic imbalance between these two can have deleterious physiological, psychological, and performance effects (Billaut, Bishop, Schaerz, & Noakes, 2011; Kellmann, 2010; Kenttä & Hassmén, 1998; Laurent et al., 2011; Meeusen et al., 2013). The monitoring of recovery is, therefore, of upmost importance to individuals and practitioners for maximizing adaptations to resistance exercise. A variety of tools have been proposed to monitor athletes including performance tests, heart rate variability, biomarker analyses, and subjective questionnaires. Regardless of what is used, monitoring tools need to be quick and easy to use, be sensitive to measuring changes in training load only, be non-invasive, cost-effective inexpensive, and accessible (Halson, 2014; Meeusen et al., 2013).

The use of multi-item questionnaires as a load monitoring tool is an attractive option for practitioners, as they satisfy many of the criteria stated above. As such, a variety of questionnaires have been used and/or developed to monitor the stress response of athletes to training. For example, the profile of mood states (POMS) questionnaire is multi-item questionnaire developed to assess the current psychological state of an individual by assessing 6 different constructs (McNair, Lorr, & Droppleman, 1971). While not originally intended to be used as a load monitoring tool, the POMS was found to share a strong relationship with total load in competitive swimmers over the course of a season (Morgan, Brown, Raglin, O'connor, & Ellickson, 1987). Athlete specific questionnaires have also been developed (e.g., Total Quality Recovery [TQR], Recovery-Stress Questionnaire for Athletes [REST-Q], and Daily Analyses of Life Demands of Athletes [DALDA]) (Kellmann & Kallus, 2001; Kenttä & Hassmén, 1998; Rushall, 1990) and share a relationship with training load (Coutts & Reaburn, 2008; González-Boto, Salguero, Tuero, González-Gallego, & Márquez, 2008; Pinto, Menezes, Fortes, & Mortatti, 2018). For a more complete list of subjective questionnaires used to monitoring stress and load, readers are directed to a systematic review by Saw, Main, and Gastin (2016). However, these subjective questionnaires often employ multiple items (i.e., questions) and the application of extended questionnaires on a daily basis may lead to subject fatigue and questionable accuracy of the measure (Galesic & Bosnjak, 2009; Rolstad, Adler, & Rydén, 2011). It may be that shorter, single item questionnaires would satisfy both the criteria needed in a monitoring tool while also decreasing the likelihood of survey fatigue. Recently, the perceptual recovery status (PRS) scale was developed as a psychophysiological tool to assess recovery from exercise. In brief, the PRS scale is single item, 0-10 ordinal scale in which athletes are asked to rate their recovery and expected performance. A score of 0 would denote that an individual is very poorly recovered and is expecting extremely poor performance where a 10 would mean that they are very well recovered and expecting optimal performance. Interestingly, Helms et al. (2018) observed survey fatigue in multi-item scales when they found that the 34-question DALDA questionnaire was not sensitive to changes in external load over 8 w of training while PRS was. The authors observed that less attention and time was given to the 34-question survey as individuals progressed throughout the study, highlighting the potential benefits that a single item scale has when applied longitudinally. Thus far, PRS was found to correlate strongly with creatine kinase (a marker of cellular damage) and share mirror changes in repetitions completed following a bout of resistance exercise. While previous research has quantified the relationship between PRS and repeated sprint performance (Laurent et al., 2011) and suggested the efficacy of PRS as a recovery metric following resistance training (Helms et al., 2018; Korak, Green, & O'Neal, 2015; Sikorski et al., 2013), the relationship between PRS and performance has not yet been quantified following resistance training.

The detrimental effects of overtraining are well known by both practitioners and researchers. As such, much of the recovery research is allocated to daily and longitudinal monitoring of athletes. However, recovery between sets of exercise is an important factor that can influence performance both acutely (Richmond & Godard, 2004; Willardson & Burkett, 2006) and chronically (Robinson et al., 1995; Schoenfeld et al., 2016). Recovery between sets of exercise is often prescribe using time based, goal specific recovery intervals. Unfortunately, the standardization of recovery using time intervals does not adequately address the inter-individual differences in recovery between sets of exercise (Machado, Pereira, & Willardson, 2012; Silva et al., 2010). Recently, studies have demonstrated relationships between PRS and performance recovery between sets of repeated sprinting (Tolusso, Laurent, Fullenkamp, & Tobar, 2015; Tomko, Laurent, Fullenkamp, Voth, & Young, nd), as well as the efficacy of PRS based rest intervals between sets of exercise (Laurent et al., 2017). It appears that the subjective nature of the scale allows for individuals to gauge how well they are recovered and their expectation of future performance. Therefore, individualization of inter-set rest periods may be achieved using PRS, allowing for a greater recovery of performance between sets of exercise which, applied longitudinally, may allow for greater physiological adaptations (e.g., muscle hypertrophy, strength, and power). As of yet, no study has evaluated the relationship between PRS and recovery of performance between sets of resistance exercise.

Fatigue, recovery, and performance are all interconnected constructs. In fact, fatigue and recovery are often defined and identified in terms of “a loss in performance” (Bishop, Jones, & Woods, 2008; Kellmann, 2010; Kellmann & Kallus, 2001). It seems appropriate then to assess these constructs using performance tests, more specifically non-fatiguing performance tests (e.g., countermovement jump, bar velocity, and isometric leg extension) (Bartolomei et al., 2017; González-Badillo & Sánchez-Medina, 2010; Sanchez-Medina & González-Badillo, 2011; Wang et al., 2016). The non-fatiguing nature of these tests means that they will not impede performance in subsequent workouts and they can be incorporated and completed quickly within a training session. The reliability of these tests have been evaluated to ensure that they are sensitive enough to detect the minimal changes in performance that occur as a result of fatigue (Cormack, Newton, McGuigan, & Doyle, 2008; De Witt et al., 2018; García-Ramos, Haff, Padial, & Feriche, 2018; Sole, Hamrén, Milosavljevic, Nicholson, & Sullivan, 2007). However, these studies often use individuals who are in a non-fatigued state, a condition that rarely occurs during training. Fatigue has been shown to increase neuromuscular and movement variability which could have deleterious effects on reliability (Contessa, Adam, & De Luca, 2009; Enoka, Robinson, & Kossev, 1989; Garland, Enoka, Serrano, & Robinson, 1994; Holtermann, Grönlund, Karlsson, & Roeleveld, 2009; Johnson, Edwards, Van Tongeren, & Bawa, 2004). Consequently, this will decrease the stability and sensitivity of the performance test (Taylor, Cronin, Gill, Chapman, & Sheppard, 2010; Weir, 2005). Practitioners would then have to perform multiple attempts to allow the metric to stabilize which would negate the benefits of the test. It is not yet understood how acute fatigue may impact the reliability of these tests and therefore, the accuracy as metrics to monitor load.

Therefore, the specifics aims of this dissertation are twofold: first, to assess the validity of perceptual recovery status (PRS) as a marker of daily and inter-set recovery during and following resistance training, and second, to assess the reliability of recovery monitoring tools in various states of fatigue.

Studies 1 and 2 will address Aim 1, specifically:

Study 1: Evaluate the validity of PRS as a subjective marker of short-term recovery following a fatiguing high-volume back squatting protocol.

We *hypothesize* that PRS would share a strong relationship with performance metrics used to assess daily recovery, as quantified by the repeated measures correlation coefficient.

Study 2: Evaluate the validity and reliability of PRS as a subjective marker of acute (inter-set) recovery during a fatiguing high-volume back squatting protocol.

We *hypothesize* that PRS would share strong relationships with performance metrics used to assess set quality, as quantified by the repeated measures correlation coefficient.

Study 3 will address Aim 2, specifically:

Study 3: Investigate the influence of fatigue on the stability of performance indices assessed over 72 h of recovery following a fatiguing high-volume back squatting protocol.

We *hypothesize* that fatigue would be inversely associated with reliability estimates of each performance test, such that reliability estimates would be lower when assessed in a fatigued state.

CHAPTER 2

THE VALIDITY OF PERCEPTUAL RECOVERY STATUS AS A MARKER OF DAILY RECOVERY FOLLOWING A HIGH-VOLUME BACK SQUATTING PROTOCOL

Abstract

Though a variety of recovery tools have been developed, many are impractical for daily use due to cost, time, and ease of interpretation. Recently, the perceptual recovery status scale (PRS) was developed as a quick, non-invasive tool to assess recovery status. The aim of this study was to assess the utility of the PRS scale to track measures of recovery up to 72 hours following a high-volume squatting protocol. Ten resistance trained men reported to the laboratory for a total of five sessions. The first session was used to establish 1-reptition maximum (1RM) for the back squat and to familiarize the participants with a non-fatiguing performance testing battery (i.e., countermovement vertical jumps, back squat at 70%1RM, isokinetic knee extension, and isometric mid-thigh pull. Participants returned to the lab 48-72 hours later to complete a fatiguing bout of exercise consisting of eight sets of 10 back squats at 70%1RM with two minutes of recovery between each set. Non-fatiguing performance measures and PRS were assessed at baseline, 24, 48, and 72 h following the high-volume squatting protocol. Repeated measures correlations revealed significant (all $p < .001$) strong, correlations between PRS and countermovement jump ($r = .86$), peak ($r = .64$) and mean bar velocity ($r = .74$), isokinetic leg extension peak torque ($r = .61$), and isometric mid-thigh pull peak force ($r = .62$). The current findings suggest that PRS can used as a method to assess daily recovery in

athletes following a fatiguing bout of resistance exercise. As with other perceptual scales, caution is stressed when comparing PRS scores of individuals.

Keywords: Recovery, Performance, Perception, Resistance Training, Monitoring

Introduction

Recovery is a complex construct that involves the assessment of numerous physiological and psychological indicators (Hooper, Mackinnon, & Howard, 1999; Kenttä & Hassmén, 1998; Laurent et al., 2011; Morgan, 1994). As such, an array of instruments and techniques have been created in an attempt to accurately assess various aspects of recovery (Bartolomei et al., 2017; Coutts, Slattery, & Wallace, 2007; Saw, Main, & Gastin, 2016). In laboratory settings, biomarkers of stress and muscle damage are often used to assess physiological strain. However, these methods are impractical for daily athlete monitoring for several reasons, including the lack of environmental control in a field-setting, accessibility to specialized equipment and personnel for collecting and analyzing samples, and like any assessment tool, the concern for high inter- and intra-subject variability (Mougios, 2007; Todd, Simpson, Estis, Torres, & Wub, 2013).

In field-settings, physiological strain is often assessed by comparing the results from physical fitness tests performed at any point during the season or training period to values obtained previously at peak or optimal performance (i.e., change from "baseline"). While this may seem to be a more convenient and practical method, this too has its limitations. For example, this method requires maximal or near-maximal effort when performing these tests, making it an inappropriate assessment tool for athletes who experience intermittent or chronic periods of exhaustion during their competitive season (Bishop, Jones, & Woods, 2008). Multi-item psychological questionnaires have been developed to subjectively quantify stress and recovery from exercise and have been used in both laboratory as well as field settings (Kellmann & Kallus, 2001; Kenttä & Hassmén, 1998; Main & Grove, 2009). The length of the questionnaire and the nature of the questions must be carefully considered as longer time requirements to complete a survey (or many surveys) can be burdensome (Rolstad, Adler, & Rydén, 2011) which in turn, could affect compliance and data quality (Galesic & Bosnjak, 2009). Therefore, many of the existing methods to gauge recovery status exhibit poor ecological validity, so more appropriate field-based measures need to be validated to address this concern.

The perceptual recovery status (PRS) scale was developed as a practical way to assess recovery status of an individual and estimate subsequent performance (Laurent et al., 2011). The PRS scale is a single item, 0-10 scale with 2 sets of verbal anchors defining the numerical indicators of both recovery and expected performance. A score of zero indicates that the individual is "very poorly" recovered and may perform poorly whereas a score of 10 would denote that the athlete is fully recovered and will perform optimally. Though limited empirical research exists exploring PRS, the few studies addressing this topic have revealed encouraging results. For example, PRS is strongly correlated with changes in sprint performance following 24, 48, and 72 h after a repeated sprinting protocol (r = -.63), indicating that lower PRS scores are associated with higher time to complete a repeated sprinting protocol (Laurent et al., 2011). Additionally, Korak, Green, and O'Neal (2015) found that both PRS and repetitions significantly increased from 24 to 48 h following a fatiguing resistance exercise bout in recreationally trained males with a concomitant. While a direct relationship between PRS and recovery of performance has been assessed following repeated sprinting, a similar relationship has only been theorized to exist following resistance. Therefore, the purpose of this study was to evaluate the validity of PRS as a subjective marker of short-term recovery following a fatiguing high-volume back squatting protocol. It was hypothesized that PRS would share a strong relationship with performance metrics used to assess daily recovery, as quantified by the repeated measures correlation coefficient.

Methods

Participants

Ten apparently healthy, resistance trained men were recruited for this study. An *a priori* power analysis, using G*Power (v3.9.1.4), indicated a minimum of 10 participants, with 4 repeated measures, were needed to yield a power of 0.80 for detecting a large correlation (r = .50) with significance set at $\alpha = 0.05$ (Faul, Erdfelder, Buchner, & Lang, 2009). To be included in the study, participants must have participated in resistance training for >1 year, be asymptomatic of cardiovascular, pulmonary and metabolic disease, report no musculoskeletal injuries, and been a non-smoker for at least 6 months. Sample characteristics are summarized in Table 2.1. Participants were instructed to refrain from alcohol, stimulants (e.g. caffeine), non-prescription drugs 12 h prior to participating in the study. Additionally, participants were asked to refrain from intense physical activity 72 h prior to and throughout the entirety of the study. Adherence to these guidelines was assessed by a 24-h history questionnaire completed at the beginning of each visit. No participants were excluded from the study based upon adherence to the guidelines. Written, informed consent was obtained prior to participation and the study was approved by the University's institutional review board.

Experimental Procedures

Baseline Testing. Participants visited the laboratory on 5 separate occasions (1 familiarization session and 4 testing sessions) in this repeated measure design (see Figure 2.1). Testing session were completed within 1 h of waking up, with all testing sessions occurring at the same time each day (±30 min) to control for diurnal variations in performance and any additional confounding factors that may impact performance.

The first visit to the laboratory consisted of obtaining anthropometric measures, establishing a 1-repetition maximum (1RM) on the back squat, and familiarizing the participants with the performance protocol. Standing height was recorded to the nearest 0.1 cm via a manual stadiometer (Seca 213, Seca Ltd., Hamburg, Germany) and nude body mass was recorded to the nearest 0.1 kg using a digital scale (Tanita BWB-800, Tanita Corp., Tokyo, Japan). Additionally, body fat percentage was calculated using a 3-site skinfold technique (Jackson & Pollock, 1978; Siri, 1956). Following anthropometric assessments, participants completed a dynamic warm-up protocol that consisted of 5 min of low intensity cycling and 10 repetitions for each of the following: bodyweight squats, walking lunges and dynamic hamstring and quadriceps stretch. Next, participants completed 3 warmup sets of the back squat in following order: 5-10 repetitions at ~50%1RM, 3 repetitions at ~85%1RM, and 1 repetition at ~90%1RM (Hoffman, 2012). Determination of 1RM was established using incremental weight increases upon successful completion of an attempt. Briefly, in the event of a successful lift, participants were given 3-5 min of recovery before completing the next attempt in which the load was increased by 10-20%. If an attempt was unsuccessful than the load was dropped by 5-15% and participants were asked to attempt the weight following 3-5 min of recovery. This protocol was continued until failure which occurred within 5 attempts for all participants. (Hoffman, 2012).

Non-fatiguing Performance Recovery Measures. Participants returned to the laboratory 3-10 d after the familiarization session to take part in the testing trials, with recovery assessed using 6 non-fatiguing performance measures as follows: 1) the PRS scale; 2) countermovement jumps; 3 and 4) peak and mean bar velocity of the back squat at 70% 1RM; 5) isokinetic maximal concentric activation during extension of the knee; and 6) isometric mid-thigh pull. The methods of the measures are detailed in the subsequent paragraphs.

Participants were asked to complete the same dynamic warm-up protocol that was performed during the familiarization session before being asked to provide a subjective indication of how their recovery status using the PRS scale (Laurent et al., 2011). Before providing a score, a researcher presented the PRS scale to the participants and gave a thorough explanation of the scale using the provided verbal anchors.

Following the subjective assessment of recovery, 3 countermovement jumps were performed with 1 min of recovery between each jump. Participants were instructed to stand on a pair of portable force plates with their hands anchored to their hips and perform a maximal vertical jump (Kistler 9286BA 10kN, Switzerland). Jump height was calculated using peak take-off velocity (Measurement, Analysis & Reporting Software, Kistler Group, Switzerland). The mean of all 3 attempts was calculated and used in the subsequent analyses.

Next, participants completed 2x1 back squat at 70%1RM with 3 min of recovery between each set. Participants were instructed to perform each back squat using maximal effort. A linear force transducer was fixed to the barbell and participants stood fully upright in order to calibrate the transducer's starting position (Gymaware, Kinetic Performance Technology Pty. Ltd., Australia). Peak and mean bar velocities were recorded for each attempt, with the mean of each metric from the 2 attempts being calculated to use in later analyses.

Participants were also fitted to an isokinetic dynamometer per the manufacturer's specification (Humac Norm Computer Sports Medicine Inc., Stoughton, MA), before performing 3 maximal concentric contractions at 180°/s with 3 min of rest between each set. The average peak torque for the 3 attempts was computed for later statistical analyses.

Last, participants were asked to perform 2, 6-s mid-thigh pulls with 3 min of recovery between each attempted. A barbell was placed above the force plates so that the participant's feet were positioned in the center of the plates and secured to the underside of the safety rails in a power rack (Kistler 9286BA 10kN, Switzerland). Participants were affixed to the bar via wrist straps and asked to take the position similar to the second pull of a power clean with knee and hip angles of 125° and 145°, respectively (Beckham et al., 2018; Enoka, 1979). A goniometer was used to ensure that these angles are maintained throughout the entirety of the study (Elite Medical Instruments, Fullerton, CA). Participants were instructed to pull the bar upwards as forcefully as possible while maintaining appropriate form throughout the attempt. Peak force was recorded for each attempt and then averaged for each timepoint.

Fatiguing High-Volume Back Squatting Protocol. Following the non-fatiguing performance testing battery, participants completed a high-volume back squatting protocol, consisting of 8 sets of 10 (8x10) at 70%1RM with 2 min of recovery between each set, designed to induce fatigue. The protocol was explained to the participants beforehand with a verbal and physical description of what was deemed a successful repetition. A successful repetition was considered to be when the participant's thighs were parallel to the floor in the eccentric portion of the lift and then return to their original starting position with hips and knees fully extended during the concentric portion of the lift. One researcher was positioned to the side of the participant to ensure that adequate depth was reached throughout the entirety of the protocol. A second researcher was positioned behind the participant as a spotter. The spotter was present to ensure participant safety should the form begin to deteriorate due to fatigue rather than provide assistant with completion of repetitions (i.e., forced reps) should the participant fail. In the event of protocol deviations, one warning was given to the participant in each set before incomplete repetitions were discounted. If a participant failed to complete a set, they were given 30 s of rest before completing the remaining repetitions for the set. In the event that 3 failed attempts occurred within a given set, the set concluded, a 2-min recovery timer was started, and the load was decreased by 10% before starting the next set. Any repetitions that were not completed within the eight sets were added to an additional set to ensure that each participant completed a total of 80 repetitions. Participants then returned to the laboratory 24, 48, and 72 h after the baseline trial to complete the non-fatiguing testing battery again (Figure 2.1).

Statistical Analysis

One-way repeated measures ANOVAs were performed to determine if a main effect is observed for recovery scores for bar peak and mean bar velocity, countermovement jump height, peak torque during isokinetic knee extension, and RFD for mid-thigh pull. When appropriate, post-hoc analyses were performed using Tukey's HSD test and analyzing all possible comparisons. Sphericity was assessed using Mauchly's test with a Greenhouse-Geisser correction being applied if sphericity was violated. Additionally, normality of error variance was evaluated using the Shapiro-Wilk test and visual examination of error plots. Lastly, individual repeated measures correlations were used to assess the intra-individual correlations between PRS and peak and mean bar velocity, countermovement jump height, peak torque during isokinetic knee extension, and mid-thigh pull peak force across baseline, 24, 48, and 72 h recovery timepoints. This method allows for the modeling of a common association between 2 measures over time, while adjusting for differences between individual participants. All data were be analyzed using SPSS version 24.0 (SPSS Inc., Chicago, IL, USA) and R version 3.4.0.1 using the *rmcorr* package (Bakdash & Marusich, 2017). Statistical significance was determined a priori at $\alpha \leq 0.05$. Data are presented as mean ± SD unless otherwise stated.

Results

Perceptual Recovery Status

Assumptions of normality for PRS were met through examination of Q-Q plots and the Shapiro-Wilk test for all timepoints ($p > .05$) except 24 h ($p = .014$). Mauchly's test revealed PRS data satisfied the assumption of sphericity ($p = .057$). Results from the repeated measures ANOVA revealed a significant main effect for time on PRS ($F_{3,27} = 28.89$, $p < .001$, $1\text{-}\beta = 1.00$, $\eta p^2 = .76$). Post-hoc analyses revealed that PRS scores at baseline were higher than all other time points ($p < .05$), indicating that subjects perceived their recovery status to be highest at baseline than following the fatiguing high-volume squatting protocol. No differences were observed between the 24 h and 48 h timepoints ($p = .792$); however, PRS scores increased from 48 h to 72 h ($p = .005$) and PRS at 72 h was higher than PRS recorded at 24 h ($p < .001$; Figure 2.2).

Non-fatiguing Performance Recovery Measures

Repeated measures correlational analyses revealed moderate-to-strong associations between PRS and the non-fatiguing performance tests (r = .61 to .86, all p < .001) and are summarized in Table 2.2. The results of the performance testing battery across time (baseline and 24 h, 48 h, and 72 h recovery) are also summarized in Table 2.2 and discussed in greater detail below.

Countermovement Jump. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated data were normally distributed at baseline and 72 h, however normality was violated at 24 h (p = .031) and 48 h (p = .045). The assumption of sphericity was assessed and found to not be violated (p = .167). Results of the repeated measures ANOVA revealed a significant effect of time on countermovement jump height ($F_{3,27}$= 18.00, p < .001, 1-β = 1.00, ηp^2 = .67) (Figure 2.3). As expected, post-hoc analyses revealed that countermovement jump performance was higher at baseline than all other time-points (p < .05). Countermovement jump height did not improve between 24 h and 48 h (p = .642) or between 48 h and 72 h (p = .437); countermovement jump height tended to be higher at 72 h than at 24 h, however, this difference was not significant (p = .053) (Figure 2.3). PRS correlated most strongly with countermovement jump height when compared to other non-fatiguing performance tests (r = .86, p < .001), this relationship is displayed in Figure 2.4.

Peak Bar Velocity. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that peak bar velocity was normally distributed at all timepoints (p > .05). Results from Mauchly's test indicated that sphericity was violated (p < .001), thus a Greenhouse-Geisser correction was applied. A repeated measures ANOVA revealed a significant effect of time on peak bar velocity ($F_{1.55,13.95}$ = 5.54, p = .023, 1-β = .90, ηp^2 = .38). Post-hoc analyses revealed that peak bar velocity was higher at baseline when compared to 24 h (p = .003) and 48 h (p = .043), but not 72 h (p = .136), suggesting that subjects had recovered based on their performance at baseline. No significant improvements in peak bar velocity were observed between 24 h and 48 h (p = .658) or 48 h and 72 h (p = .642). Moreover, we did not observe differences in peak bar velocity between 24 h and 72 h (p = .334) (Table 2.2). Lastly, there was a moderate association between PRS and peak bar velocity.

Mean Bar Velocity. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that mean bar velocity was normally distributed across all timepoints (p > .05). Mauchly's test indicated that sphericity was violated (p < .001), thus a Greenhouse-Geisser correction was applied. A repeated measures ANOVA revealed a significant effect of time on mean bar velocity ($F_{1.35,12.135}$ = 9.76, p < .001, 1-β = .99, ηp^2 = .52). Post-hoc analyses revealed that mean bar velocity decreased following the baseline testing session and remained depressed throughout 24 h (p < .001) and 48 h (p = .023) and rebounding by 72 h (p = .08). Additionally, mean bar velocity did not change from 24 h to 48 h (p = .122) or 48 h to 72 h (p = .943). Mean bar velocity reported at 24 h was lower than at 72 h (p = .037). Lastly, there was a moderate-to-strong association between PRS and mean bar velocity.

Isokinetic Knee Extension – Peak Torque. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that mean bar velocity was normally distributed across all timepoints (p > .05). Mauchly's test indicated that sphericity was violated (p = .002) therefore a Greenhouse-Geisser correction was applied. A repeated measures ANOVA revealed a significant effect of time on peak torque ($F_{1.45,13.02} = 9.07$, $p = .006$, 1-β = .99, $\eta p^2 = .50$). Subsequent pairwise comparisons revealed peak torque generated during baseline testing was higher than reported at any other time point ($p < .05$); however, no differences were observed during the recovery period ($p > .05$ for 24, 48, and 72 h). Repeated measures correlation revealed that a moderate association between PRS and peak torque generated during isokinetic knee extension (Table 2.2).

Mid-thigh Pull – Peak Force. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that mean bar velocity was normally distributed across all timepoints ($p > .05$). Additionally, Mauchly's test indicated that the assumption of sphericity was met ($p = .70$) A repeated measures ANOVA revealed a significant effect of time on mean bar velocity ($F_{3,27} = 5.35$, $p = .005$, 1-β = .91, $\eta p^2 = .36$). Pairwise comparisons revealed that peak force during the mid-thigh pull decreased following the baseline session and remained as such at both 24 h ($p = .01$) and 48 h ($p = .05$). However, peak force returned to baseline by 72 h ($p = .909$). No improvements in peak force were observed from 24 h to 48 h ($p = .896$) or 48 h to 72 h ($p = .190$); however, peak torque was higher at 72 h than 24 h ($p = .047$). Consistent with other non-fatiguing performance tests, PRS was moderately associated with peak torque generated during mid-thigh pull (Table 2.2).

Discussion

While a multitude of tools and metrics have been developed to assess recovery, each with their own set of limitations, some more apparent when applied in sports performance setting among a group or team of athletes. Within this context, it is important to identify quick, easy to implement, and accurate monitoring tools that can be used to supplement existing performance indices and be used as a stand-alone tool for assessing daily recovery status. Thusly, the purpose of this study was to determine the concurrent-criterion validity of the PRS scale as a marker of recovery of performance following a bout of high-volume resistance exercise in trained males. Though the association between the PRS scale and surrogate measures of recovery following resistance exercise have been explored (Korak et al., 2015; Sikorski et al., 2013), this appears to be the first study designed with the specific intention to quantify such a relationship. It was hypothesized that PRS would share a strong relationship with performance metrics as assessed by the repeated measures correlation coefficient. Perceptual recovery status yielded strong correlations (r = .61 to .84) with peak and mean bar velocity, countermovement jump height, peak force during isometric mid-thigh pull, and peak torque during isokinetic knee extension following a high-volume squatting protocol. Overall findings from this study suggest that PRS is a valid metric to gauge physiological recovery status following high-volume resistance exercise.

Recovery is a complex construct involving a myriad of physiological and psychological indicators, with a correspondingly high number of metrics developed to assess individual indicators. The current study defined recovery from a practical perspective where the product of these indicators would manifest themselves as decrements in performance (Bishop et al., 2008). Performance can also be defined in a variety of ways, and as such, multiple assessments of neuromuscular performance were used to thoroughly evaluate recovery of performance. These metrics were chosen based upon high degrees of reliability (Cormack, Newton, McGuigan, & Doyle, 2008; De Witt et al., 2018; Moir, Sanders, Button, & Glaister, 2005; Sole, Hamrén, Milosavljevic, Nicholson, & Sullivan, 2007) and their direct (González-Badillo & Sánchez-Medina, 2010; Sanchez-Medina, Perez, & Gonzalez-Badillo, 2010) or indirect relationship (De

Witt et al., 2018; Jidovtseff, Harris, Crielaard, & Cronin, 2011; Watkins et al., 2017) with outcomes associated with neuromuscular performance.

All performance metrics used in the current study shared a similar trend from baseline throughout 72 h. That is, a significant decrement in performance was observed 24 h following the fatiguing protocol when compared to baseline performance. Additionally, all performance metrics remained suppressed 48 h after the fatiguing protocol with all metrics except isokinetic knee extension peak torque and vertical jump height returning to baseline following 72 h of recovery. These results are in direct contrast to those of Bartolomei et al. (2017) who found that the same performance variables used in the current study were not significantly different than baseline by 48 h. Divergent findings may be explained by squatting proficiency as assessed by 1RM. Average 1RM in the current study was 155 kg while Bartolomei et al. (2017) reported an average 1RM of 173 kg. Although both studies employed similar guidelines for what they considered resistance trained, it is hypothesized that enhanced familiarity, despite the increased total load, for the enhanced recovery. Regardless, the data suggest that the fatiguing protocol provided a strong enough stimulus and homeostatic disruption that participants needed approximately 72 h to recover.

As can be seen in Figure 2.2, PRS significantly decreased 24 h and remained as such 48 h, following the fatiguing protocol, signifying that PRS is sensitive to perturbation to homeostasis 24 h following a stressor. This is not surprising and indeed expected due to similar trends detected in the objective measures used in the current study and previous literature supporting a similar notion in both resistance exercise (Korak et al., 2015; Sikorski et al., 2013) and repeated sprint work (Laurent et al., 2017; Tolusso, Laurent, Fullenkamp, & Tobar, 2015; Tomko, Laurent, Fullenkamp, Voth, & Young, nd). Korak et al. (2015) observed significant decrements in both performance and PRS 24 h after a multi-exercise resistance bout with PRS and performance significantly increasing after 48 h of recovery in a group of resistance trained males. Interestingly, the decrements in PRS reported by Sikorski et al. (2013) following a multi-exercise resistance exercise protocol were higher than reported in the current investigation and by Korak et al. (2015), despite the similar samples used. It may be that higher number of sets by Sikorski et al. (2013) induced systemic disturbances than that observed by Korak et al. (2015) which would explain the greater decrements in PRS. Also, the fatiguing protocol employed in the current study placed a greater total volume on a less musculature when compared to Sikorski et al. (2013), suggesting that PRS may be amplified by efferent feedback from multiple muscle groups and be able to assess recovery status of the entire body.

As previously stated, large correlations between PRS and all performance metrics were observed in the current study. However, there was also considerable range in the correlation coefficients, .61 to .86, suggesting that careful consideration should be given to the type (or types) of non-fatiguing performance tests used to evaluate recovery in relation to the initial stressor or stimuli (in this case, a high-volume back squatting protocol) as PRS performed better as a recovery metric for movements that more closely mimicked the back squatting protocol. Indeed, it appeared that PRS correlated more strongly with dynamic, multi-joint movements similar to that of the squat, with PRS correlating most strongly with mean bar velocity and countermovement jump height. Not only are these movements more dynamic in nature, but the resistance trained men recruited for this study were likely more familiar with these types of movements compared to, for example, isokinetic knee extension. Although we are the first to design a study aimed at directly quantifying the relationship between PRS and recovery of performance following resistance exercise, one other study reported similar findings between

PRS and recovery from repeated sprinting (Laurent et al., 2011), while another study used alternative recovery metrics but observed a similar relationship during recovery from resistance exercise (Sikorski et al., 2013). For example, Laurent et al. (2011) assessed the correlation between the PRS scale and performance recovery at 24, 48, and 72 h following a repeated sprinting protocol. The change in sprint time shared a correlation of $r = -.63$ to PRS, which indicated the time to complete a sprint increased with lower PRS scores. Additionally, Sikorski et al. (2013) found PRS to correlate strongly with creatine kinase and muscular soreness 48 h following a multi-exercise resistance bout. While plasma creatine kinase concentration is the product of release and clearance, and may not be a direct assessment of muscle damage, numerous studies have found elevated creatine kinase levels following a bout of high-volume resistance exercise and associated decreases in performance (Bartolomei et al., 2017; Byrne & Eston, 2002). Therefore, it was not surprising, and indeed expected that PRS would correlated highly with recovery of performance following a high-volume resistance protocol.

Table 2.3 displays a frequency distribution of PRS scores along with a crude indicator of performance recovery. While there is an observable trend of increasing PRS values denoting increased levels of performance recovery, one can also see the variability of recovery within an individual PRS score. For example, a PRS score of 6 was given eight times throughout the entirety of the study which coincided with objective recovery scores ranging from 84-100%. To look at it from an objective standpoint, there were a total of 19 timepoints in which participants produced recovery scores of 95-100%. Within this same recovery range, PRS scores varied from 5-10. While this appears to call in to question the validity of PRS, a couple of considerations must be accounted for. Firstly, objective recovery was calculated based upon performance during the baseline testing session with the assumption that abstinence from resistance training at least

72 before testing would permit complete physiological recovery and maximized performance. However, performance and recovery are both multi-dimensional constructs that involve both physiological and psychological components (Hooper et al., 1999; Kenttä & Hassmén, 1998; Meeusen et al., 2013; Morgan, 1994). While participants were given general guidelines to control for these multiple components, physiological and psychological parameters inhibiting performance could only be controlled to a certain extent. It may be that participants were not able to give a true maximal performance during the baseline testing session and reported PRS scores that mirrored that and could explain the range of PRS scores reported during baseline testing. Secondly, the subjective nature of perceptual scales is understood to exhibit inter-individual variability and should be considered on an individual basis rather than applied to the entire group (Garcin, Vautier, Vandewalle, Wolff, & Monod, 1998; Robinson, Robinson, Hume, & Hopkins, 1991; Whaley, Brubaker, Kaminsky, & Miller, 1997). The results of the sensitivity analysis in combination with the repeated measure correlation analyses appear to validate this notion. For example, a PRS score of 6 may mean a different level of performance recovery between 2 individuals, but the relationship between PRS and objective recovery of performance markers appear to be stable within an individual.

Though this study designed to assess the applicability of PRS rather than the physiological mechanisms that mediate it, we can briefly hypothesize some of these mechanisms based upon another subjective scale used in exercise physiology, rating of perceived exertion (RPE). Rating of perceived exertion is a psychophysiological scale aimed at providing a subjective experience of effort during exercise. As such, RPE shares correlations with a variety of peripheral measures including HR, pain, and ventilation (Chen, Fan, & Moe, 2002), as well as psychological factors (Morgan, 1973). More recently, RPE was shown to correlate with increased activity in areas specific to motor control as well (De Morree, Klein, & Marcora, 2012). While debate exists arguing whether RPE is derived from afferent feedback, central motor command, or a combination, the influence of afferent feedback is stressed in all models (Pageaux, 2016). Indeed, RPE has been hypothesized to be both the conscious manifestations of afferent physiological feedback and psychological sensations, as well as a primary regulator of exercise performance (Hampson, Gibson, Lambert, & Noakes, 2001; Tucker, 2009). It may be that PRS acts similarly, but as an estimation of future performance based on the current physiological and psychological state rather than the manifestation of current physiological and psychological distress and regulator of current performance. Because PRS is being assessed at rest, afferent information may differ from that used to generate an RPE. Future research should delve into the impact of measures of motivation and arousal on PRS, as well as muscular soreness, swelling, and tightness.

Limitations and Future Research

While findings from the current study are promising, the generalizability of our findings are limited in scope and additional research on the widespread utility of PRS as a subjective measure of recovery status is warranted. Practitioners and researchers should exercise caution when using PRS in practice, incorporating it as a supplement to other measures of recovery and readiness to perform. The current study assessed the accuracy of PRS following a fatiguing high-volume back squatting protocol indicative of a hypertrophy type of resistance exercise workout. The greater total volume often observed in hypertrophy workouts has been shown to increase muscular damage, soreness, and pain in subsequent days than more “typical” resistance exercise routines (Bartolomei et al., 2017). It may be that increases in pain and soreness sensation, not generally observed to the same extent in higher volume routines, acted as an additional feedback component that helped participants delineate their PRS following the fatiguing protocol. Additional research is required in order to assess the accuracy of PRS following strength and power based (i.e., high intensity, low volume) routines. Also, the study employed well rested participants in a protocol that took place over the course of 4 d while periodized training involves months/years of training with athletes experiencing a range of fatigue and recovery. Further research is needed to determine if the accuracy of PRS can be maintained throughout the course of periodized training regimen employing multiple exercises and muscle groups. Nevertheless, findings from the current study do show that trained individuals can accurately assess recovery of performance using PRS.

Conclusion

The present study is the first to quantify the relationship between PRS and recovery of performance following a bout of high-volume back squatting protocol. Strong correlations were observed between PRS and all performance metrics when accounting for between-subject variability. These results support the use of PRS as a daily metric of recovery following resistance exercise in resistance trained males. Nonetheless, the generalizability of our findings are limited in scope and additional research on the widespread utility of PRS as a subjective measure of recovery status is warranted.

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Table 2.1

Descriptive Characteristics of Sample (n = 10)

Metric	Mean ± SD
Age (y)	22.0 ± 1.7
Height (cm)	179.9 ± 8.3
Weight (kg)	88.5 ± 10.1
Body fat (%)	13.2 ± 4.1
BMI (kg/m^2)	27.7 ± 2.8
1RM Squat (kg)	154.9 ± 30.5

BMI, Body mass index. 1RM, 1-repetition maximum

Table2. 2

Non-fatiguing Performance Metrics Across Time and Repeated Measures Correlation with Perceptual Recovery Status (n = 10)

Metric	r (95%CI)	Time			
		Baseline	24 h	48 h	72 h
Peak Bar Velocity (m/s)	.64 (.42-.79)*	1.22 ± 0.15	1.04 ± 0.29†	1.09 ± 0.23†	1.12 ± 0.21
Mean Bar Velocity (m/s)	.74 (.54-.88)*	0.68 ± 0.07	0.56 ± 0.13†	0.61 ± 0.1†	0.62 ± 0.09‡
Isokinetic Knee Extension Peak Torque (Nm)	.61 (.41-.78)*	158.47 ± 25.93	127.33 ± 28.14†	131.17 ± 34.46†	135.12 ± 34.56†
Mid-thigh Pull Peak Force (N)	.62 (.37-.77)*	3051.93 ± 660.27	2860.14 ± 677.51†	2899.22 ± 704.35†	3014.66 ± 730.21‡

Note:* Denotes a significant correlation between performance metric and PRS (p < .001); † Denotes a significant difference from baseline; ‡ Denotes a significant difference from 24 h

Table 2.3

Frequency Distribution of Perceptual Recovery Status Scores in Relation to Mean Recovery Score (n=10)

PRS	Mean Recovery Score[a]						
	65-70%	70-75%	75-80%	80-85%	85-90%	90-95%	95-100%
3	2	1		3			
4			1	1	1		
5			1		2	3	1
6				1	1	3	3
7						1	2
8							5
9							6
10							2

[a] Recovery score was calculated as the average recovery score of peak bar velocity, mean bar velocity, peak torque from isokinetic knee extension, peak force from mid-thigh pull, and vertical jump recovery scores at each timepoint.

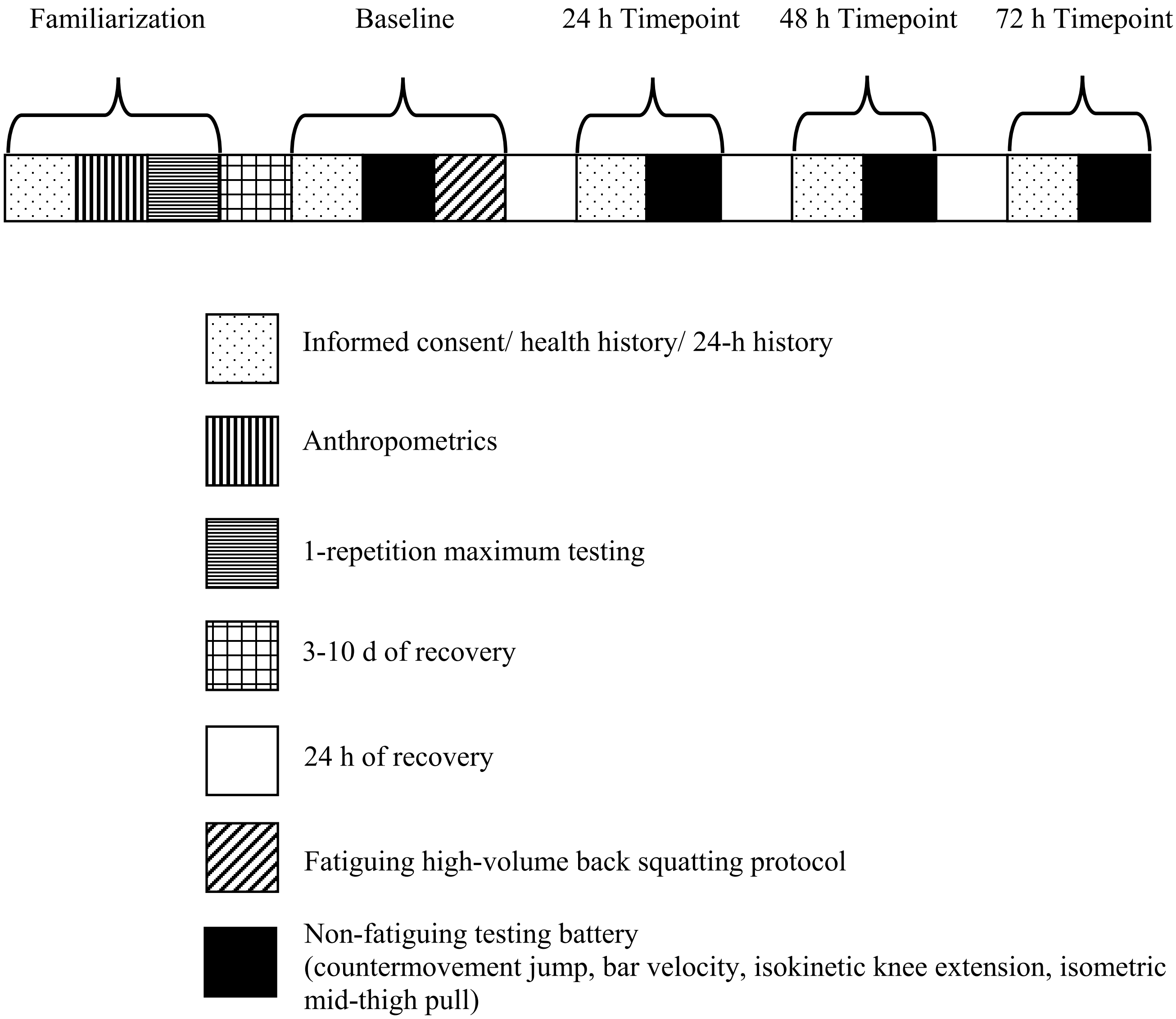

Figure 2.1. Schematic illustration of study protocol

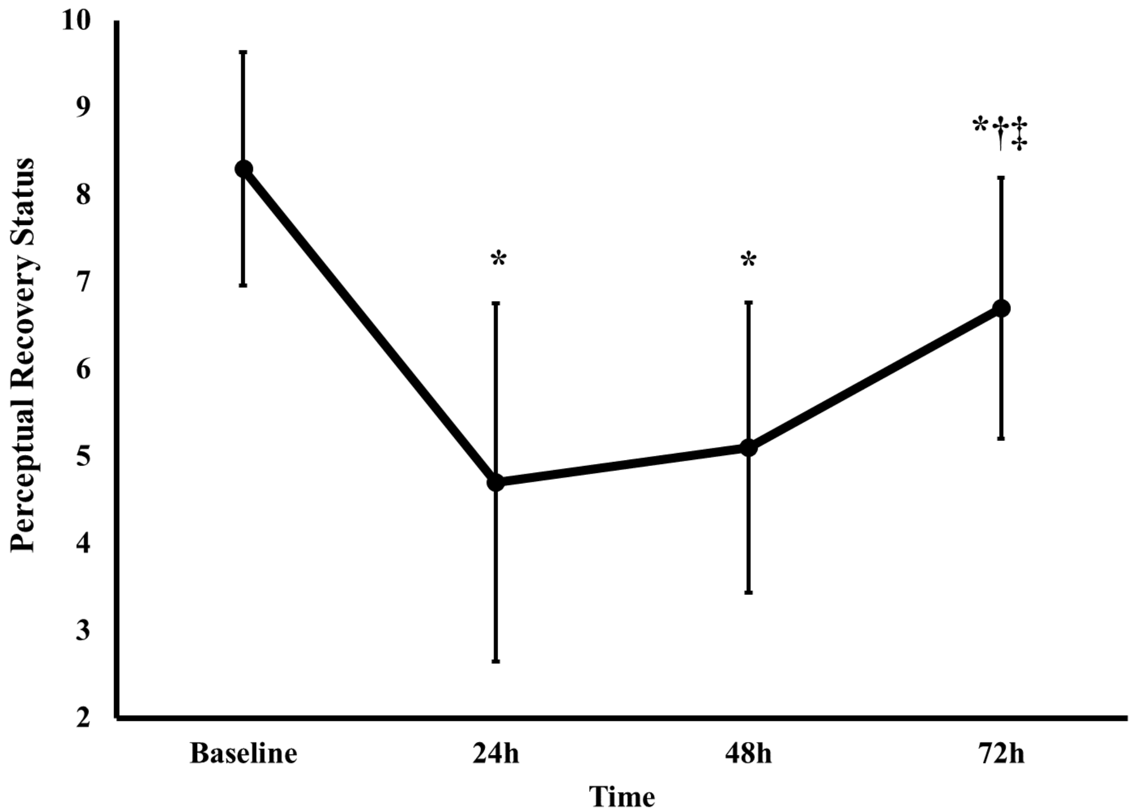

Figure 2.2. Perceptual recovery status reported before and 24, 48, and 72 hours following a high-volume squatting protocol
Note: * Denotes significant difference from baseline; † Denotes significant difference from 24 h; ‡ Denotes a significant difference from 48; all $p < .05$

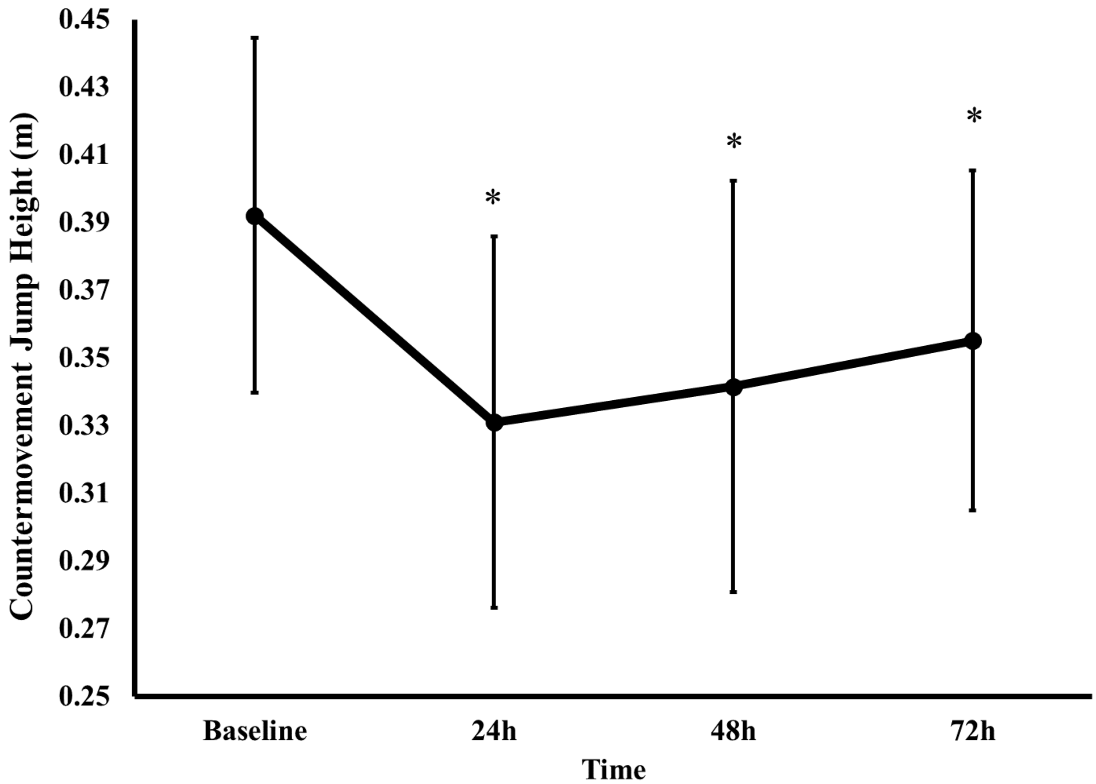

Figure 2.3. Countermovement jump height recorded before and 24, 48, and 72 hours following a high-volume squatting protocol
Note: * Denotes significant difference from baseline (*p* < .05)

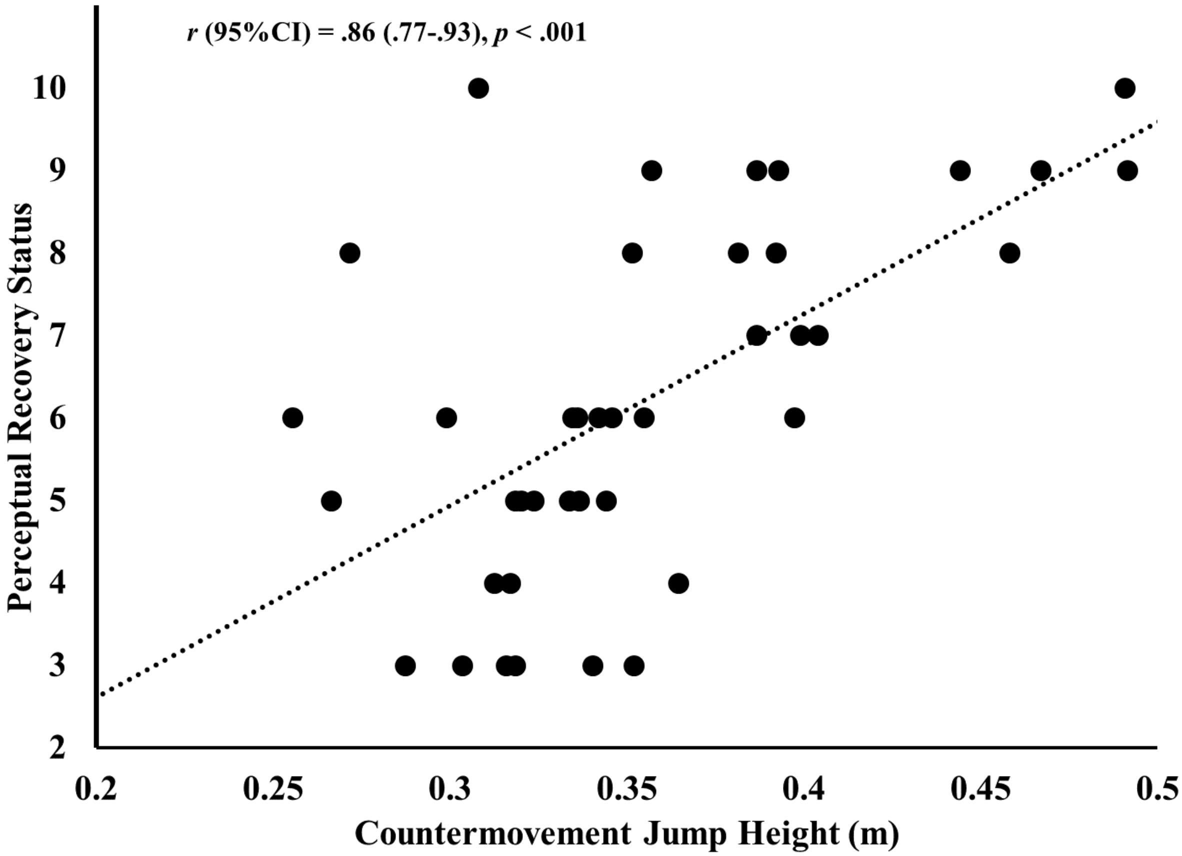

Figure 2.4. Scatterplot depicting the relationship between perceptual recovery status and countermovement jump height before and 24, 48, and 72 hours following a high-volume squatting protocol

CHAPTER 3

THE VALIDITY OF PERCPETUAL RECOVERY STATUS AS A MARKER OF INTER-SET RECOVERY DURING A HIGH-VOLUME BACK SQUATTING PROTOCOL

Abstract

Time-based inter-set recovery may not allow adequate recovery for during multi-set exercise due to variability in recovery between individuals. Recently, the perceptual recovery status scale (PRS) was created to assess recovery of a person and may be utilized to regulate inter-set recovery periods. The aim of the current study was to evaluate the accuracy of PRS as a measure of performance recovery between sets resistance exercise. Ten resistance-trained men were recruited for the study. The protocol consisted of 4×10 back squats at 70% 1-repetition maximum with inter-set rest periods of 2 min. Mean and peak bar velocities were recorded for each rep of the testing session and PRS was assessed with 30 s remaining in the inter-set rest period. Repeated measures ANOVAs were used to analyze the changes in PRS, mean and peak bar velocity, and decrements in mean and peak bar velocity. Repeated measures correlations were conducted to assess the relationship between PRS and mean and peak bar velocity, as well as their decrements. A significant time-effect was observed, such that PRS and mean bar velocity metrics decreased through subsequent sets. PRS was found to correlate strongly with mean bar velocity (r = .65), peak bar velocity (r = .55), and decrements in mean (r = -.67) and peak bar velocity (r = -.56; all p <.05). The results indicate that PRS is a predictor of set to set performance and can potentially be used to program inter-set rest periods. Due to the individual differences in subjective measures, this should be done on an individual basis.

Keywords: Recovery, Perception, Inter-set, Prescription

Introduction

Resistance training is a crucial component to any structured fitness program aimed at maintaining or improving physical performance. Successful resistance training programs should consider variables such as training volume and recovery time when prescribing resistance exercise to elicit adequate adaptation. While monitoring load and recovery between days of training is often emphasized by practitioners and researchers, far less attention is allocated towards monitoring recovery between sets of exercise within a given exercise session (de Salles et al., 2009). However, gaining a greater understanding of rest intervals needed between sets of exercise would allow practitioners to optimize training to ensure that athletes are receiving the required time needed to recover and maintain performance throughout a training bout.

While general guidelines for goal-specific rest intervals have been proposed (ACSM, 2009; Garber et al., 2011; Sheppard & Triplett, 2015), these do not account for the variability in recovery between individuals (Machado, Pereira, & Willardson, 2012; McCann & Flanagan, 2010; Silva et al., 2010). This is problematic because it is during these rest intervals that allow for the recovery of energy systems (rephosphorylation of adenosine diphosphate and creatine), clearance of metabolic byproducts and consequently, acute recovery of performance (Larson Jr & Potteiger, 1997). The assumption that all athletes in a team-sport recover at a similar rate will undoubtedly lead to diminished performance in subsequent sets of an exercise bout by some individuals. This concept is extremely important because inadequate rest intervals cause significant reductions in performance both acutely (Abdessemed, Duche, Hautier, Poumarat, & Bedu, 1999; Ratamess et al., 2007; Richmond & Godard, 2004) and chronically (de Salles et al., 2010; Robinson et al., 1995). For example, Richmond and Godard (2004) found that inter-set rest periods of 1,3, and 5 min were not adequate to allow for the maintenance of repetitions over 2 sets of bench press. In contrast, Kraemer (1997) found that 3 min of recovery between sets of squat and bench press allowed for the maintenance of repetitions across 3 sets of exercise. This consistent underperformance due to inadequate rest intervals may eventually manifest as sub-optimal adaptations to resistance training (Robinson et al., 1995).

While the previously mentioned studies provide evidence of population level differences in acute recovery times, findings also support the notion of difference in acute recovery needs within a homogenous population. For example, Pereira et al. (2009) found that individualized critical rest intervals (CRI), i.e., the shortest rest period between sets needed in order to maintain performance, improved performance in a group of 10 regional-level athletes who had been training for at least 4 years. Specifically, CRI based rest intervals allowed for a greater number of countermovement jumps, a greater time to exhaustion, and a greater amount of total work to be completed when compared to standardized rest intervals of 4,5, and 6 s. Results indicated that the average rest time needed between jumps was 7.5 ± 1.6 s, however the range of CRIs was 5.3 s (5.2-10.5), a two-fold difference in required rest time between 2 participants from a similar population. Additionally, Dabbs, Muñoz, Tran, Brown, and Bottaro (2011) revealed that the rest period needed to stimulate the greatest post-activation potentiation response was highly variable across the 30 recreationally trained participants in their sample. Given the substantial inter- and intra-individual variability observed in acute recovery responses, the use of subjective indices of recovery may be more efficacious in gauging an *individual's* true recovery status rather than implementing the "one-size fits all" approach to recovery that is often recommended in various exercise and performance guidelines (ACSM, 2009; Garber et al., 2011; Sheppard & Triplett, 2015).

Originally, perceptual recovery status (PRS) was developed as a marker to assess the daily recovery of individuals (Laurent et al., 2011). More recently, PRS has been used as a subjective metric to gauge self-selected inter-set recovery periods. Laurent et al. (2017) found that self-selected rest intervals between bouts of repeated sprinting yielded performance improvements of 8-12% in recovery of power between sets, lesser decrements in power within a set, and a higher power output through the trial when compared to a standardized recovery period of 5 min. It is plausible that similar trends would be observed with resistance training. Before that question can be answered, however, the accuracy of PRS as metric for the assessment of inter-set recovery in resistance training is warranted. Therefore, the purpose of this study was to evaluate the validity and reliability of PRS as a subjective marker of acute (inter-set) recovery during a fatiguing high-volume back squatting protocol. We hypothesize that PRS would share strong relationships with performance metrics used to assess set quality, as quantified by the repeated measures correlation coefficient.

Methods

Participants

Ten apparently healthy, resistance trained men were recruited for this study. An *a priori* power analysis, using G*Power (v3.9.1.4), indicated a minimum of 10 participants, with 4 repeated measures, were needed to yield a power of 0.80 for detecting a large correlation (r = .50) with significance set at $\alpha = 0.05$ (Faul, Erdfelder, Buchner, & Lang, 2009). As such, 10 apparently healthy men were recruited to participate in the current study. Sample descriptive characteristics are provided in Table 3.1. To be included in the study, participants must have not smoked in the previous 6 months, participated in moderate to vigorous resistance training for >1 year, been asymptomatic of cardiovascular, pulmonary and metabolic disease, and report no musculoskeletal injuries. All participants' informed consent was acquired and with the study being approved by the University's institutional review board. Participants were instructed to refrain alcohol, stimulants (e.g. caffeine), and non-prescription drugs 12 h prior to familiarization and testing sessions. Additionally, participants were asked to avoid intense physical activity for at least 72 h prior to testing sessions. Adherence to these guidelines, as well as sleep and diet information was assessed by a 24-h history questionnaire completed prior to every trial. No participants were excluded from the study based upon adherence to the guidelines.

Procedures

Familiarization Session. The current study required participants to come into the laboratory on 2 separate occasions, once for a familiarization session and the other being the testing session. The first laboratory visit was used to familiarize participants with the protocol, collect anthropometric and descriptive data, and assess the individuals' 1-repetition maximum (1RM) on the back squat that was to be used during the subsequent laboratory session. Upon arrival, subjects were assessed for height (cm) and nude body mass (kg), using a manual stadiometer (Seca 213, Seca Ltd., Hamburg, Germany) and digital scale (Tanita BWB-800, Tanita Corp., Tokyo, Japan) to the nearest 0.1 cm and kg, respectively. Estimations of body fat percentage were also performed using the 3-site method (chest, abdomen, and thigh) by skinfold calipers (Lange, Cambridge, Maryland, USA) (Jackson & Pollock, 1978; Siri, 1956). Next, participants completed a dynamic warm-up protocol that consisted of 5 mins of low intensity cycling and 10 repetitions of the following: bodyweight squats, walking lunges, and dynamic hamstring and quadriceps stretches. Following a standardized dynamic warm-up, participants completed 3 warmup sets of back squat in the following order: 5-10 repetitions at ~50%1RM, 3 repetitions at ~85%1RM, and 1 repetition at ~90%1RM. Participants then completed an incremental protocol in which load is increased (approximately 2-12 kgs) upon competition of an attempt. Each attempt was separated by 3-5 min of recovery. When appropriate, 2 attempts were given to complete a lift before ending the session. The highest weight successfully completed was recorded as the 1RM.

Testing Session. Participants returned to the laboratory within 3-10 d of the familiarization session to complete the testing session. Participants completed the same standardized dynamic warm-up as the familiarization session and 3 sets of squats at a self-selected intensity before being queried as to their perceptual recovery status (PRS). Briefly, PRS is assessed using a 0-10 scale with verbal indicators detailing both recovery of the individual recovery status and expected performance. For example, a score of 0 denotes that the participant is poorly recovered expects weak performance, where a score of 10 denotes that an individual is very well recovered and is expecting optimal performance. Following the warm-up, participants performed a fatiguing back squat protocol consisting of 4 sets of 10 (4×10) back squats at 70%1RM interspersed with 2 min of recovery between each set. A successful repetition was when the participant's thighs were parallel to the floor in the eccentric portion of the lift and then return to their original starting position with hips and knees fully extended during the concentric portion of the lift. One warning was given to the participant in each set before incomplete repetitions were not counted. Additionally, a spotter was positioned behind the participant as a safety precaution but did not aid in the completion of any reps. Perceptual recovery status was also obtained approximately 30 s before beginning subsequent set. Throughout the protocol, a linear force transducer (Gymaware, Kinetic Performance Technology Pty. Ltd., Australia). was attached to the bar to assess bar velocity metrics, specifically peak bar velocity and mean bar velocity.

Calculation of Decrement Scores

Decrement scores were calculated to assess the decrease in mean and peak bar velocity across a sequence of 10 consecutive repetitions. Raw peak and mean bar velocity data recorded from each set were transformed into decrement scores using the following equations (Fitzsimons, Dawson, Ward, & Wilkinson, 1993; Moir, Graham, Davis, Guers, & Witmer, 2013):

Decrement in mean bar velocity (%) = $\left(1 - \left(\frac{Sum\ of\ mean\ bar\ velocities\ within\ a\ set}{fastest\ mean\ bar\ velocity * 10}\right)\right) * 100$

Decrement in peak bar velocity (%) = $\left(1 - \left(\frac{Sum\ of\ peak\ bar\ velocities\ within\ a\ set}{fastest\ peak\ bar\ velocity * 10}\right)\right) * 100$

Therefore, a high decrement score denoted a greater decrease in peak or mean bar velocity throughout a set of back squats.

Statistical Analysis

Repeated measures correlations were used to assess the relationship between PRS and peak and mean bar velocity, as well as the decrement scores for peak and mean bar velocity across 4 sets of exercise (Bakdash & Marusich, 2017). This method allows for the relationship between 2 variables to be modeled over time without violating the assumption of independent observations needed for a normal bivariate correlation. Additionally, a 1-way repeated measures ANOVA were performed to determine if a main effect is observed for time on peak bar velocity, mean bar velocity, decrements in peak bar velocity, decrements in mean bar velocity, and PRS.

Mauchly's test was used to test the assumption of sphericity and a Greenhouse-Geisser correction was applied when the assumption was violated. When appropriate, repeated contrasts were carried out in which timepoints were compared to the timepoint immediately before it (e.g., PRS before set 1 vs. PRS before set 2), to determine if there were any significant changes between timepoints. The Shapiro-Wilk test was used to assess normality of the data. All data was analyzed using R version 3.4.0.1 (*rmcorr package;*) and SPSS version 24.0 (SPSS Inc., Chicago, IL, USA). Statistical significance was determined a priori at $\alpha \leq 0.05$. Data are presented as mean ± SD.

Results

Perceptual Recovery Status

Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that PRS was normally distributed across all timepoints ($p > .05$). Mauchly's test indicated that the assumption of sphericity was met ($p = .200$). A repeated measures ANOVA revealed a significant effect of time on PRS ($F_{3, 27} = 38.47$, $p < .001$, $1\text{-}\beta = 1.00$, $\eta p^2 = .81$). Repeated contrasts revealed that reported PRS values continued to decrease throughout all 4 sets of back squat ($p < .05$). Mean PRS values for all sets are outlined in Figure 3.1.

Raw Bar Velocity

Mean Bar Velocity. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that mean bar velocity was normally distributed across all timepoints ($p > .05$). Mauchly's test indicated that the assumption of sphericity was met ($p = .139$). A repeated measures ANOVA revealed a significant effect of time on mean bar velocity ($F_{3, 27} = 6.06$, $p =$

.003, 1-β = .93, ηp^2 = .40). Repeated contrasts revealed that mean bar velocity decreased from the first to second set (p < .022), with no other differences between sets being observed (p < .05; Figure 3.2). Results from a repeated measures correlation comparing mean bar velocity and PRS found that the two variables had a positive, high correlation (r [95%CI] = .65 [.46-.82]; p < .001). A visual depiction of this relationship is shown in Figure 3.3.

Peak Bar Velocity. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that mean bar velocity was normally distributed across all timepoints (p > .05). Mauchly's test indicated that the assumption of sphericity was met (p = .382). A repeated measures ANOVA revealed a significant effect of time on peak bar velocity ($F_{3, 27}$ = 1.37, p = .275, 1-β = .32, ηp^2 = .132). Planned contrasts revealed there were no differences when comparing peak bar velocity within a set to the set directly previous (p > 0.05; Figure 3.4). Repeated measures correlations revealed a strong, positive relationship between the two variables whereas PRS score decreased, so too did peak bar velocity (r [95%CI] = .55 [.37-.76]; p = .001).

Decrements in Bar velocity

Mean Bar Velocity. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that decrement of mean bar velocity was normally distributed across all timepoints (p > .05). Mauchly's test indicated that the assumption of sphericity was met (p = .129). A repeated measures ANOVA revealed a significant effect of time on mean bar velocity ($F_{3, 27}$ = 6.06, p < .001, 1-β = .99, ηp^2 = .52). Planned contrasts revealed that decrements in mean bar velocity increased from the first to second set (p = .042) and the third to fourth set (p = .010), but not the second to third set (p = .189; Figure 3.2). Additionally, the relationship between the decrement in mean bar velocity within a set and PRS shared a strong, negative correlation where PRS score decreased as individuals saw a higher rate of fatigue within a set (r [95%CI] = -.67 [-.82 - -.53]; p < .001).

Peak Bar Velocity. Visual inspection of the Q-Q plot and results of the Shapiro-Wilk test indicated that decrement of peak bar velocity was normally distributed for set 1 and 2 (p > .05) but was not normally distributed for set 3 (p < .001) or set 4 (p = .003). Additionally, Mauchly's test indicated that the assumption of sphericity was violated (p = .001), so a Greenhouse-Geisser correction was applied. A repeated measures ANOVA revealed a significant effect of time on decrement in peak bar velocity ($F_{1.33,\ 11.93}$ = 3.17, p = .093, 1-β = .67, ηp^2 = .26). Planned post-hoc analyses revealed there were no differences when comparing decrement in peak bar velocity within a set to the set directly before it (p > 0.05; Figure 3.4). A strong negative correlation was revealed between PRS and decrements in peak bar velocity where PRS scores indicated a greater drop in peak bar velocity within a set of exercise (r [95%CI] = -.56 [-.79 - -.34]; p = .001).

Discussion

Inter-set rest periods are an important component to any strength training program. The dissipation of fatigue through adequate recovery between sets of resistance training allows for enhanced both acute and chronic resistance training performance. However, standardized rest periods do not adequately address the variability in acute recovery between individuals. Therefore, there is a necessity for a tool to allow for the individualization of recovery between sets of exercise. The purpose of this study was to determine the utility of PRS as a predictor of subsequent set performance during a high-volume squatting protocol. Though the association between the PRS scale and surrogate measures of recovery following resistance exercise have been explored (Korak, Green, & O'Neal, 2015; Sikorski et al., 2013), this is the first study to specifically quantify these relationships with the intent to establish the validity of PRS as a metric of recovery between sets of resistance exercise. Consistent with our hypothesis, we found that PRS shared strong correlations with mean peak and mean bar velocity of a set, as well as the decrement of peak and mean bar velocity within a set. Taken together, the findings from our study support that PRS is sensitive enough to detect changes in performance and the quality of performance during a single bout of high-volume resistance exercise.

Participants in the current study experienced the impact of accumulated fatigue throughout the course of this protocol. As accumulated fatigue increases, trends for decreases in mean bar velocity between sets was observed as well as increases in the mean velocity lost within a set. Similar findings were observed by Tufano et al. (2016) who found that the decrements of within set bar velocity significantly increased throughout three sets and mean bar velocity was significantly lower in set 3 as compared to the first two sets. This observed decrease in bar velocity within and between sets is a well-known concept in the literature (Izquierdo et al., 2006; Oliver et al., 2016; Sanchez-Medina & González-Badillo, 2011; Tufano et al., 2016) and has been hypothesized to be due to peripheral metabolic factors (Allen, Lamb, & Westerblad, 2008; Sanchez-Medina & González-Badillo, 2011; Westerblad, Allen, & Lannergren, 2002) and central neurological factors (Brownstein et al., 2017; Gandevia, 2001). However, more recent research points to the interplay between these two systems in which metabolic factors stimulate nociceptive receptors in the periphery which in turn mediate efferent output to working muscle as a mechanism to decrease fatigue and the consequent perturbations to homeostasis (Amann, Proctor, Sebranek, Pegelow, & Dempsey, 2009; Blain et al., 2016; Burnes, Kolker, Danielson, Walder, & Sluka, 2008). If one subscribes to this idea of fatigue then it is not surprising that a subjective scale, theorized to be the manifestation of psychophysiological strain, correlates strongly with neuromuscular performance and indicates decrement in performance as fatigue begins to accumulate (Laurent et al., 2011). The decrements in PRS and performance have previously been observed during repeated sets of sprint work (Tolusso, Laurent, Fullenkamp, & Tobar, 2015; Tomko, Laurent, Fullenkamp, Voth, & Young, nd). Therefore, it stands to reason that perceptually mediated rest intervals using PRS could be used as a method for prescribing individually tailored inter-set rest intervals that enable exercisers to maintenance performance throughout a resistance exercise session.

The relationship between bar velocity metrics and PRS has practical applications for resistance exercise prescription, specifically, in terms of individualizing inter-set recovery periods, which would allow for adequate recovery and increased performance over the course of multiple sets within a single exercise bout. Multiple studies have shown the impact that longer rest periods (i.e., increased recovery) have on the optimization of performance (Abdessemed et al., 1999; Kraemer, 1997; Ratamess et al., 2007; Richmond & Godard, 2004; Willardson & Burkett, 2005, 2006). Indeed, longer rest periods have allowed greater total volume to be completed within a bout of exercise (Willardson & Burkett, 2005) and maintenance of load, volume, and power (Abdessemed et al., 1999; Ratamess et al., 2007). If these trends were to be extrapolated over the course of an entire training program it could have an immense impact on chronic adaptations due to the assurance of adequate. Schoenfeld et al. (2016) found that longer rest periods between sets of exercise allowed for greater strength increases and somewhat greater hypertrophic responses during an 8-w training program in which participants were asked to perform lifts to failure within every set. Interestingly, the authors point out that there was a large amount of within-group variability suggesting that manipulation of training variables and more specifically, rest intervals, should be done on an individual basis. It may be that the compounding effect of an increased total load, shorter between set rest periods, and similar amount of training days caused a chronic disassociation in movement quality (e.g., velocity) between the two conditions which allowed for these similar chronic adaptations with differing total volumes.

The idea of self-regulated inter-set recovery periods has been assessed in repeated sprinting (Brownstein, Ball, Micklewright, & Gibson, 2018; Glaister et al., 2010; McEwan, Arthur, Phillips, Gibson, & Easton, 2018) and resistance training (De Salles et al., 2016; Goessler & Polito, 2013; Ibbott, Ball, Welvaert, & Thompson, 2019). For example, Laurent et al. (2017) compared fixed rest intervals (5 min) and perceptually regulated recovery periods using the PRS scale in which participants were to begin the next set of exercise. Results indicated that perceptually regulated recovery periods produced increased amounts of recovery time with concomitant improvements in power, decrement scores, and recovery scores during 3 sets of repeated sprinting. Additionally, time spent in recovery increased between sets 1 and 2 and sets 2 and 3 suggesting that PRS is sensitive to the role of accumulated fatigue in recovery of performance. Indeed, this trend in increased, self-regulated, recovery time between sets of repeated sprint work has been shown elsewhere (Glaister et al., 2010; McEwan et al., 2018). Ibbott et al. (2019) also found that self-selected recovery time increased as the amount of sets increased throughout a squatting protocol. Interestingly, no differences in performance were observed between self-selected and fixed recovery periods of 3 or 5 min. However, the 3-min recovery condition resulted in the dropout of 20% of participants by the final set of the protocol and the 5-min recovery condition was found to significantly longer rest periods than that of the self-selected recovery condition. This provides evidence that perceptually regulated rest intervals may allow for a greater maintenance of performance throughout a workout while also being more time effective than longer (e.g., 5-min) rest periods. While the current study used fixed rest intervals and assessed PRS, the data suggest that self-regulated inter-set rest periods using PRS may allow for similar results as established in previous literature. While, fatigue accumulated throughout each set of exercise, so too did PRS and bar velocity metrics. Additionally, strong correlations between PRS and bar velocity metrics mean that individuals can associate a PRS score with a given bar velocity, whether consciously or subconsciously. Therefore, rest intervals mediated by PRS would suggest that the time spent in recovery would increase as the amount of sets increased, but also that bar velocity would be maintained to a greater extent than shorter, fixed rest periods.

There are obvious parallels between PRS and rating of perceived exertion (RPE) with the scaling and development of PRS being based on session RPE (Laurent et al., 2011). Interestingly, RPE has also been shown to correlate with bar velocity during the back squat, deadlift, and bench press (Helms et al., 2017) and has been successfully used to individualize training loads throughout an 8-w training cycle (Helms et al., 2018). It may be that these scales utilize similar feedback mechanisms but go about individualizing resistance training prescriptive components in opposing ways. Individualizing load based upon RPE allows for load to vary based upon the fatigue status of the individual in order maintain set quality. Conversely, PRS could be used to individualize recovery period, allowing for adequate recovery and dissipation of fatigue, which may allow for the preservation of set quality using a pre-determined load.

Limitations and Future Research

Though findings from the current study are promising, practitioners are cautioned to exercise restraint in the application of PRS as a prescription tool for inter-set rest periods. For example, this study only assessed the relationship between PRS and performance metrics following high repetitions sets of exercise, at least in comparison to most strength and power protocols. It may be that the afferent feedback following a high volume set of squats differs from that of a high intensity set. Because perceptual measures are based on afferent information, any differences in afferent feedback may mediate the relationship between PRS and recovery of performance. Additionally, the current study employed only one exercise during the workout, while most programs would have multiple exercises to stress a variety of musculature. Research has shown the exercise order during bouts with multiple exercises impact the number of repetitions completed during a bout of exercise (i.e., performance) due to whole body accumulated fatigue (Sforzo & Touey, 1996; Simão, Farinatti, Polito, Maior, & Fleck, 2005), so it is not yet understood if the relationship between PRS addresses local, task dependent recovery or if it can also address the impact that systematic fatigue has on performance. Lastly, this study employed a design in which participants were asked to estimate their PRS following a set rest period. This method is equivalent to RPE estimation in which participants are asked to estimate their exertion based upon a workload set be the researcher. In terms of applicability however, RPE production, the manipulation of exercise intensity based upon a fixed RPE value, seems to be more important. Perceptual recovery status is not any different. Therefore, while this study has shown that a relationship between PRS and performance exists, future studies should employ “PRS production” methodologies in which participants are asked to rest until they reach a predetermined PRS value.

Conclusion

The current study is the first to assess the relationship between PRS and performance metrics within a bout of resistance exercise. Strong correlations with observed between PRS and peak and mean bar velocity during the back squat, as well as the decrement in peak and mean bar velocity within sets of the back squat. While the design of the current study is not necessarily generalizable to what may occur in a bout of resistance exercise, it does provide evidence to suggest that PRS could be used to individualize inter-set recovery periods to allow for the maintenance of bar velocity through multiple sets of exercise. Nonetheless, future studies employing more ecologically valid methodology to determine PRS as a metric to gauge intrasession recovery is warranted.

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Table 3.1

Descriptive Characteristics of Sample (n = 10)

Metric	Mean ± SD
Age (y)	23.3 ± 3.5
Height (cm)	179.5 ± 7.9
Weight (kg)	89.3 ± 9.8
1-RM (kg)	151.4 ± 21.5
Body fat (%)	13.4 ± 4.2
BMI (kg/m²)	27.8 ± 3.0

BMI, Body mass index. 1RM, 1-repetition maximum

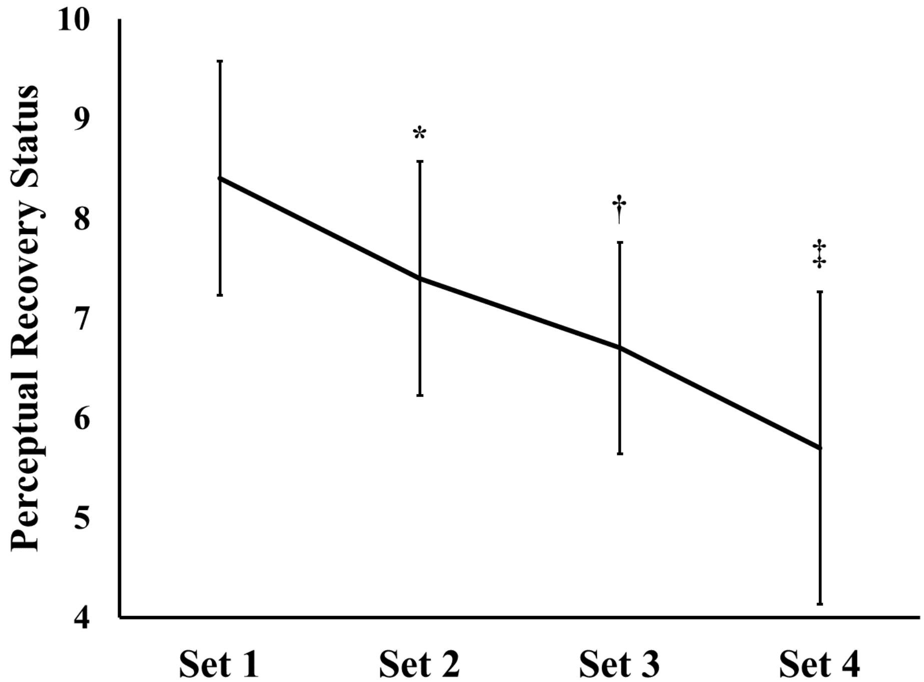

Figure 3.1. Perceptual recovery status reported immediately before each set during a high-volume squatting protocol

Note: * Denotes significant difference between set 1 and 2 ($p < .001$); † Denotes significant difference set 2 and set 3 ($p = .01$); ‡ Denotes significant difference set 3 and set 4 ($p = .004$)

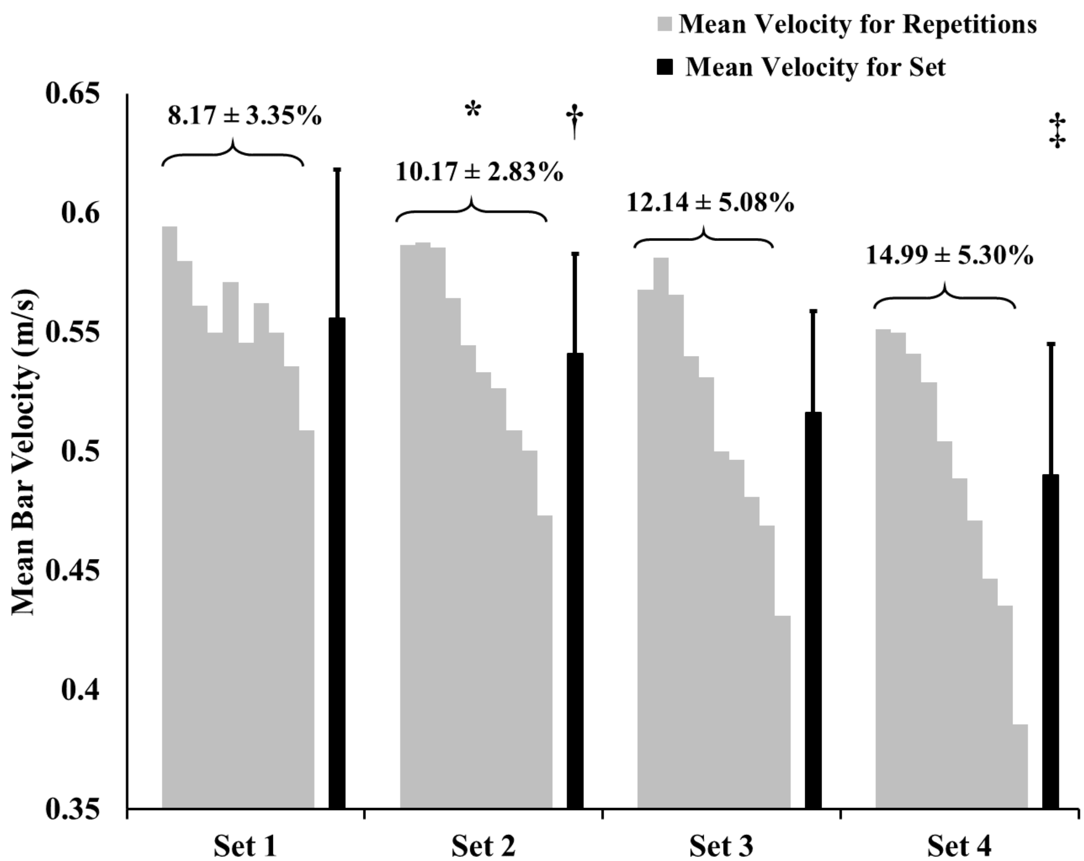

Figure 3.2. Mean bar velocity and decrement score obtained for each set during a high-volume squatting protocol

Note: * Denotes significant difference in mean bar velocity between set 1 and 2 (p = .022); † Denotes significant difference in decrement of mean bar velocity between set 1 and 2 (p = .042); ‡ Denotes significant difference in decrement of mean bar velocity between set 1 and 2 (p = .01)

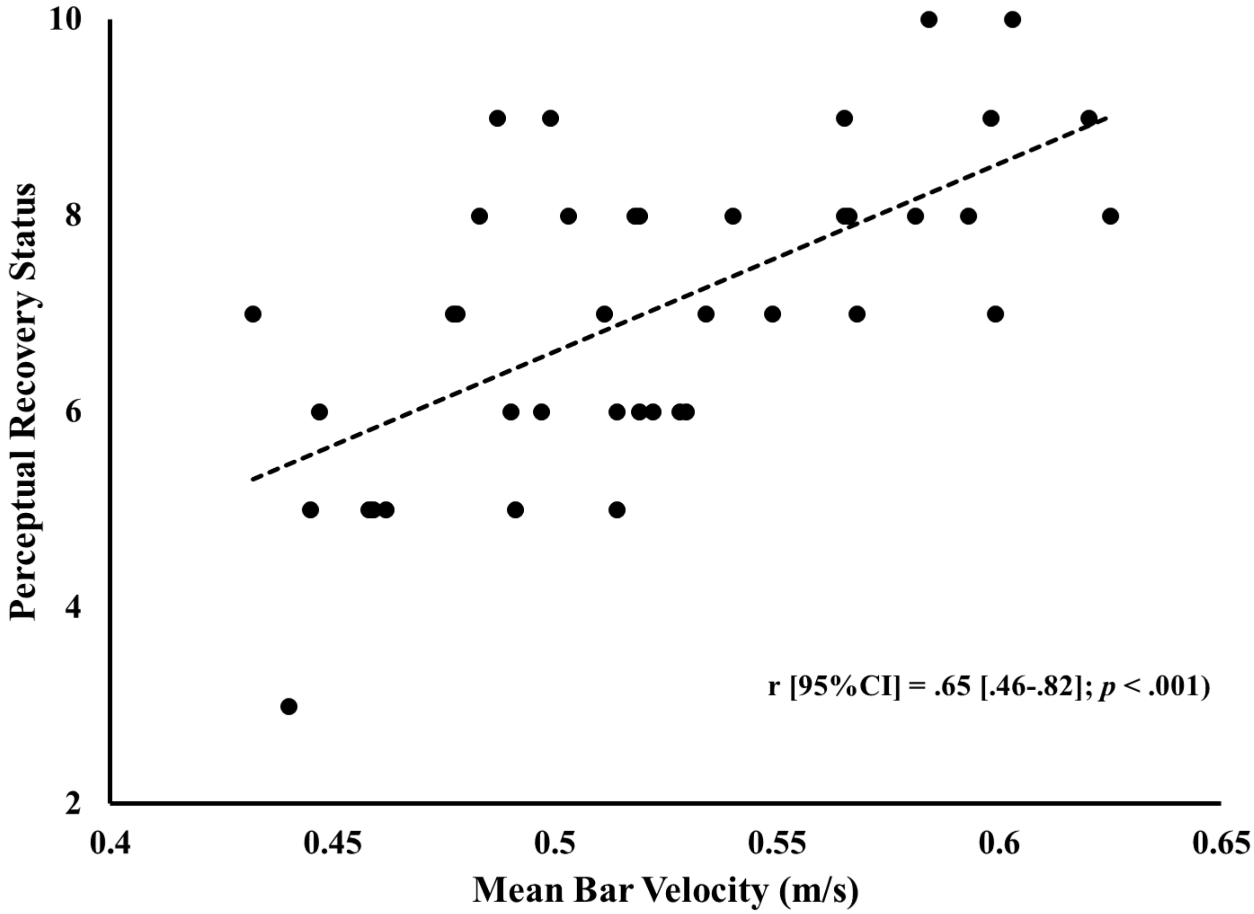

Figure 3.3. Relationship between mean bar velocity and perceptual recovery status for each set during a high-volume squatting protocol

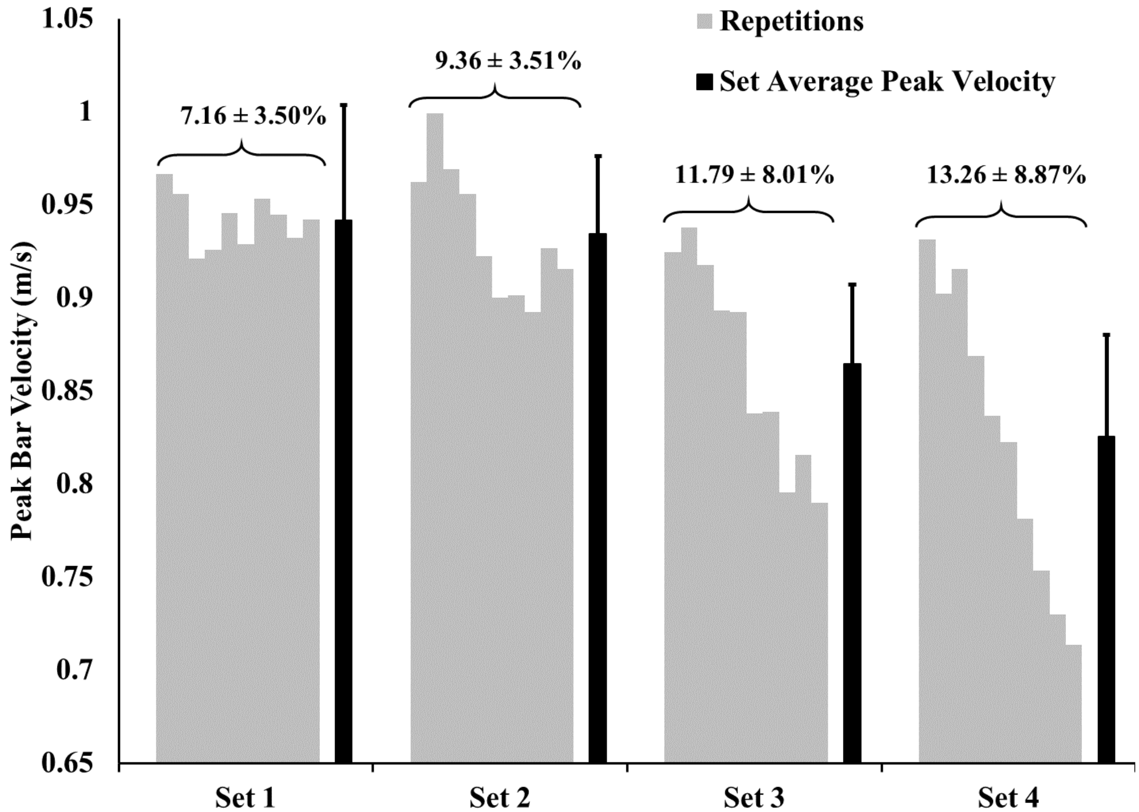

Figure 3.4. Peak bar velocity and decrement score obtained for each set during a high-volume squatting protocol

CHAPTER 4

THE IMPACT OF FATIGUE ON THE INTRASESSION RELIABILITY OF RECOVERY OF PERFORMANCE INDICES FOLLOWING A HIGH-VOLUME BACK SQUATTING PROTOCOL

Abstract

A metric used to monitor individuals during a training program must be sensitive to change and reliable. Reliability is impacted by random variability from a variety of sources including biological variability. Fatigue increases biological variability in the form of movement and neuromuscular variability. The aim of this study was to evaluate the impact that fatigue has on the reliability of a metric designed to monitor individuals during a training program. Eleven resistance trained men were recruited for the study. Individuals were asked to complete a fatiguing bout of exercise consisting of 8 sets of 10 back squats at 70%1RM with 2 min of recovery between each set. Before the fatiguing session, individuals completed a testing battery consisting of countermovement jumps, back squat at 70%1RM, isokinetic knee extension, and isometric mid-thigh pull to establish baseline performance metrics. They returned to the laboratory 24, 48, and 72 h after the high-volume squatting protocol to complete the same testing battery. Performance metrics were then used to stratify trials into 4 separate fatigue states. Intraclass correlation coefficients revealed high degrees of reliability for all performance metrics (ICC = .79-1.00). The lower bound confidence intervals of the ICC for bar velocity metrics dropped below .70 on a few instances, but this was due to homogeneity of the performance metric within those fatigue states. Absolute reliability of bar velocity indicated relatively similar

measurement error despite differences in fatigue state. Our current findings suggest that the reliability of performance metrics are not notably impacted by fatigue status.

Keywords: Reliability, Monitoring, Error, Measurement, Fatigue

Introduction

The reliability of a measure or test is an important component of measurement theory. While there are a multitude of ways to calculate it, reliability can be thought of as a ratio between the amount of variation in the true score across individuals to total amount of variability in a group of observed scores. This total variability is the sum of variability in true scores and variability due to error (e.g., constant error, bias, and random error) (Weir, 2005). It is the mitigation of these sources of error, especially random error, which increase the reliability of a measure. This is important when assessing changes in a measure over time such as assessment of training adaptations or monitoring recovery following training. Highly reliable measures display enhanced sensitivity due to the increased confidence that a change in a score is due to a true change rather than inherent variability of a measurement tool or test (Atkinson & Nevill, 1998; Hopkins, 2000).

Monitoring of recovery from a bout of exercise is paramount for coaches and practitioners for assessing the development of strength and power, as well as the accumulation of fatigue. Exercise is meant to place stress upon multiple physiological systems to elicit an adaptive response, however, excessive and prolonged overload can be counterproductive (Kellmann, 2010; Meeusen et al., 2013). While a multitude of subjective and objective markers have been used to monitor athletes, the use of non-fatiguing, neuromuscular indices of performance recovery are an attractive option for practitioners due to their simplicity, ease of interpretation, and time (Bishop, Jones, & Woods, 2008; Halson, 2014). Because these measures do not induce fatigue, they do not place additional stress upon the individual and do not need to be accounted for within a periodized program. Two of the most commonly used methods to assess neuromuscular performance and recovery are countermovement jump and bar velocity. Both measures have been shown to be reliable in active males (coefficients of variability < 8%), (Cormack, Newton, McGuigan, & Doyle, 2008; García-Ramos, Haff, Padial, & Feriche, 2018) and related to one another, as well as metabolic markers of fatigue (Pareja-Blanco et al., 2017; Sanchez-Medina & González-Badillo, 2011).

An additional component of reliability, especially popular in psychometrics, is that reliability of a measure varies by population. That is, reliability is not an all-inclusive property attached to a measure but rather a specific property of said measure in the population in which it was assessed (Hu et al., 2016; Raykov & Marcoulides, 2015). Evidence for this 'conditional reliability' exists for measures used to monitor training load based upon sex and time of day. For example, Slinde, Suber, Suber, Edwén, and Svantesson (2008) found that sex plays a role in test-retest reliability, as women reported higher intraclass correlation coefficient (ICC) values than man for countermovement jump without an arm swing (0.88 vs. 0.80), while men reported higher ICC values than women for countermovement jump with an arm swing (0.88 vs. 0.82). Additionally, Taylor, Cronin, Gill, Chapman, and Sheppard (2010) assessed the impact of time of day on variability in performance measures and found that variability was lower for jump height, peak and mean power, and peak velocity. Additionally, performance measures collected in the morning had a lower coefficient of variation when compared to the afternoon session, making morning testing preferable to afternoon testing when monitoring an athlete. The latter of the two examples demonstrates that conditional reliability may not only be conditional upon the population and time of day, but also the current physiological state of the participant.

The major issue is that the reliability of these tests is typically established at a single time-point when the participant is in a rested state, rather than at multiple time-points across a continuum of fatigue states, which is more likely the scenario individuals will be exposed to during short- and long-term training. Fatigue increases force variability (Contessa, Adam, & De Luca, 2009; Enoka, Robinson, & Kossev, 1989; Garland, Enoka, Serrano, & Robinson, 1994; Holtermann, Grönlund, Karlsson, & Roeleveld, 2009; Johnson, Edwards, Van Tongeren, & Bawa, 2004) potentially due to increased movement (Cortes, Onate, & Morrison, 2014; Duffey & Challis, 2007) and motor neuron firing rate variability (Contessa et al., 2009; Enoka et al., 1989; Garland et al., 1994). Thus, the presence of fatigue may decrease the conditional reliability of performance metrics used to monitor athletes, thus decreasing the sensitivity needed to detect changes in fatigue and recovery of an athlete. Therefore, the purpose of this study was to investigate the influence of fatigue on the stability of performance indices assessed over 72 h of recovery following a fatiguing high-volume back squatting protocol. We hypothesized that fatigue would be inversely associated with reliability estimates of each performance test, such that reliability estimates would be lower when assessed in a fatigued state.

Methods

Participants

An *a priori* power analysis indicated that a minimum of 10 participants were needed to yield a power of 0.80 for detecting an ICC of 0.75 with significance set at $\alpha = 0.05$. An ICC value of 0.75 was employed as it is regularly used as cut-off value between good and excellent agreement between measures (Cicchetti, 1994; Koo & Li, 2016). Eleven, apparently healthy men were recruited to participate in the current study. Descriptive characteristics of study participants are summarized in Table 4.1. To be included in the study, participants must have participated in resistance training for >1 year, be asymptomatic of cardiovascular, pulmonary and metabolic disease, report no musculoskeletal injuries, and been a non-smoker for at least 6 months. Participants were instructed to refrain from alcohol, stimulants (e.g. caffeine), non-prescription drugs 12 h prior to participating in the study. Additionally, participants were asked to refrain from intense physical activity 72 h prior to and throughout the entirety of the study. Adherence to these guidelines was assessed by a 24-h history questionnaire completed at the beginning of each visit. Informed consent was acquired before beginning any testing session and the study was approved by the University's institutional review board.

Procedures

Participants came into the lab on 5 separate occasions (1 familiarization session and 4 testing sessions) in this repeated-measures, within-subject design. Participants were instructed to refrain from alcohol, stimulants (e.g. caffeine), non-prescription drugs and intense physical activity 12 h prior to the familiarization session and throughout the entirety of the study. A 24-h history questionnaire was completed prior to every trial to ensure adherence throughout the study. Trials were completed within a 30-min window each day to control for diurnal variations in performance and other factors that may mediate performance.

Familiarization Session. The first session was a familiarization session in which anthropometric measures were recorded, 1-repetition maximum (1RM) on the back squat was established, and participants familiarized themselves with the performance tests they would complete throughout the entirety of the study. Height and nude weight were assessed by a stadiometer (Seca 213, Seca Ltd., Hamburg, Germany) and digital scale (Tanita BWB-800, Tanita Corp., Tokyo, Japan). A 3-site skinfold technique was then used to assess body fat percentage (Jackson & Pollock, 1978; Siri, 1956). Participants then completed a dynamic warm-up consisting of 5 min of low intensity cycling and 10 repetitions for each of the following: bodyweight squats, walking lunges, and dynamic stretches targeting the hamstrings and quadriceps. Next, a back squat specific warm-up that comprised: 5-10 repetitions at ~50%1RM, 3 repetitions at ~85%1RM, and 1 repetition at ~90%1RM. Establishment of 1RM was completed using an incremental protocol. Upon completion of a squat attempt, 3-5 min of recovery were allotted, and the load was increased by 10-20%. If a participant failed an attempt, then load would be decreased by 5-15% and another attempt would be given after 3-5 minutes of rest. The extent of load increases and decreases were determined by a certified strength and conditioning specialist (Hoffman, 2012). Back squat 1RM was established within 5 attempts for all participants.

Non-fatiguing Performance Recovery Measures. Experimental testing sessions began a minimum of 72 h after the familiarization session. Following a dynamic and squat warm-up, participants performed a series of non-fatiguing performance tests used to assess performance recovery. The series consisted of 3 countermovement jumps, 2 back squats at 70% 1RM, 3 isokinetic knee extensions and 2 mid-thigh pulls. These measures were used to establish baseline measures of performance when participants were in a completely recovered state.

Participants completed 3 countermovement jumps separated by 1 min of recovery between each jump. While standing on a pair of portable force plates, participants were instructed to perform a maximal vertical jump with their hands fixed to their hips to prevent arm swing (Kistler 9286BA 10kN, Switzerland). Jump height was calculated from peak take-off velocity for each attempt (Measurement, Analysis & Reporting Software, Kistler Group, Switzerland).

Following a 3-min recovery period, participants performed 2 repetitions of back squat at 70%1RM with 3 min of recovery between each repetition. A linear force transducer (Gymaware, Kinetic Performance Technology Pty. Ltd., Australia) attached to the outer edge of the bar was calibrated following manufacturer guidelines to set the starting position of the movement. Participants were instructed to perform a maximal velocity squat. Peak and mean bar velocity were recorded for both squat attempts and used in the subsequent analyses.

Participants were then fitted to an isokinetic dynamometer per the manufacturer's specification (Humac Norm Computer Sports Medicine Inc., Stoughton, MA), before performing 3 maximal knee extensions 180°/s with 3 min of rest between each set. The peak torque for each attempt was recorded.

Participants were asked to perform 2, 6-s mid-thigh pulls with 3 min of recovery between each attempted. A barbell was placed above the force plates so that the participant's feet were positioned in the center of the plates and secured to the underside of the safety rails in a power rack (Kistler 9286BA 10kN, Switzerland). Participants were affixed to the bar via wrist straps and asked to take the position similar to the second pull of a power clean with knee and hip angles of 125° and 145°, respectively (Beckham et al., 2018; Enoka, 1979). A goniometer was used to ensure that these angles are maintained throughout the entirety of the study (Elite

Medical Instruments, Fullerton, CA). Participants were instructed to pull the bar upwards as forcefully as possible while maintaining appropriate form throughout the attempt. Peak force was recorded for each attempt and then averaged for each condition.

Fatiguing High-Volume Back Squatting Protocol. After establishing baseline measures for the series of non-fatiguing performance tests, participants performed 8 sets of 10 (8×10) back squat at 70%1RM with 2 min of recovery between each set. Participants were given a verbal description and a physical demonstration of what was counted as a successful repetition. A repetition was considered a successful when the participant's thigh reached parallel to the floor at the end of the eccentric portion of the lift and returned to a fully upright position with knee and hips fully extended. One researcher monitored each repetition and participants were given one warning per set before repetitions were not counted for the set. Additionally, a spotter was positioned behind the participants as a safety precaution but did not aid in the completion of any repetitions. If failure within a set occurred, participants were given 30 s of rest before completing the remaining repetitions for the set. If 3 failures occurred within a set, then the set was stopped, a 2-min rest period was started, and the load on the bar was decreased by 10% and this new load was used for all subsequent sets. Any repetitions not completed after the eighth set were added to a ninth set to ensure that all participants completed a total of 80 repetitions. Participants returned to the lab 24, 48, and 72 h after the baseline trial to complete the same testing session without the fatiguing back squat protocol.

Ordering of Fatigue States

Recovery states for each person were defined by recovery scores. First, recovery scores were calculated for countermovement jump height, peak and mean bar velocity, isokinetic leg extensions, and mid-thigh pull at each timepoint for all individuals. Recovery scores allow for the standardization of recovery of performance within an individual where a score of 1 indicates complete recovery of performance and lower scores denote a less recovered state. The formula for calculating recovery score is provided below using recovery of countermovement jump height during the 24-h condition as an example.

$$\text{Percent (\%) Recovery of Countermovement Jump} = \frac{\text{Average jump height 24h condition}}{\text{Average jump height baseline condition}} * 100$$

Then, single daily recovery scores within an individual were calculated by averaging the recovery scores of each of the performance tests within a given day. This new metric was intended to denote the overall level of recovery of an individual within a given day and control for individualized recovery patterns of the participants. Daily recovery scores were ordered so the highest recovery day was denoted as FS1 and the lowest recovery condition was denoted as FS4, with raw performance metrics now being grouped by recovery condition rather than day. Average recovery scores were as follows: FS1 = 100 ± 0%; FS2 = 90.42 ± 8.00%; FS3 = 85.71 ± 11.60%, FS4 = 81.70 ± 14.70%.

Statistical Analysis

Reliability was assessed in accordance with guidelines set by Weir (2005). Multiple 1-way repeated measures ANOVA were used to determine if there were any systematic biases observed between attempts within a recovery condition. If a main effect of attempt was observed, then the data were reevaluated for trends between attempts. If the differences between attempts were regarded as non-trivial, an effect size (ES) ≥ 0.2, then they were removed (Cohen, 1992). The assumptions for normality and sphericity were evaluated using the Shapiro-Wilk and Mauchly's test, respectively. Sphericity was assessed using Mauchly's test with a Greenhouse-Geisser correction being applied if sphericity was violated. Additionally, normality of error variance was evaluated using the Shapiro-Wilk test and visual examination of error plots.

To assess the impact of fatigue on relative reliability of performance metrics, 2-way fixed effect intraclass correlation coefficients (ICC 3,1) for relative agreement was calculated. Additionally, the standard error of the measurement around the true score (SEM) was estimated for each performance as a measure of absolute reliability (Dudek, 1979; Weir, 2005). Lower SEM values indicated less variability around the true score and a higher degree of repeatability and confidence that differences are due to real changes in performance rather than inherent variability due to the test. Minimum detectable differences (MD) was also be calculated as measure to define the difference needed between to measures to consider the change real rather than an artifact of biological variability with 90% confidence. Each performance metric had a total of 4 ICC, SEM, and MD values: FS1, FS2, FS3, and FS4. All data were be represented as mean ± standard deviation unless otherwise specified. Statistical significance was determined a priori at $\alpha \leq 0.05$. All data were analyzed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Calculations for ICC and SEM are detailed below.

$$\mathrm{ICC} = \frac{\mathrm{MS_S} - \mathrm{MS_E}}{\mathrm{MS_S} + (\mathrm{K}-1)\mathrm{MS_E}}$$

$$\mathrm{SEM} = \mathrm{SD}_{GM}\sqrt{\mathrm{ICC}(1-\mathrm{ICC})}$$

$$\mathrm{MD} = \mathrm{SEM} * 1.64 * \sqrt{2}$$

Where MS_S indicates the subjects mean square, MS_E indicates the error mean square, K is the number of trials for each participant, and SD_{GM} is the standard deviation of the grand mean

Results

Countermovement Jump

Visual inspection of the Q-Q plots and results of the Shapiro-Wilk tests indicated that all attempts were normally distributed except for attempt 2 of the FS4 condition (p = .044). The assumption of sphericity was assessed and found to not be violated for any recovery condition (p > 0.05). Results of the repeated measures ANOVA revealed no main effect for attempt on countermovement jump height for FS1 (p = .328), FS2 (p = .286), FS3 (p = .191), or FS4 (p = .171). Additionally, countermovement jump was found to be reliable across all conditions. Table 4.2 outlines reliability statistics and mean values for each condition.

Bar Velocity

Mean Bar Velocity. Visual inspection of the Q-Q plots and results of the Shapiro-Wilk tests indicated that all attempts were normally distributed (p > .05). The assumption of sphericity was also accepted for all recovery conditions (p > .05). Results of the repeated measures ANOVA revealed no main effect for attempt on mean bar velocity for FS1 (p = .396), FS2 (p = .778), FS3 (p = .822), or FS4 (p = .908). Mean bar velocity was found to be reliable across all conditions. Table 4.3 outlines reliability statistics and mean values for each recovery condition.

Peak Bar Velocity. All attempts were found to be normally distributed except for attempt 1 of the FS1 condition based upon visual inspection of the Q-Q plot and results of the Shapiro-Wilk test (p = .026). Additionally, a Greenhouse-Geisser correction was applied for the FS4 condition for violating the assumption of sphericity (p = 0.017). However, sphericity was not violated at any other time recovery condition (p > 0.05). Results of the repeated measures

ANOVA revealed no main effect for attempt on peak bar velocity for FS1 (p = .275), FS2 (p = .815), FS3 (p = .553), or FS4 (p = .860). Reliability statistics and mean values for peak bar velocity, separated by condition, can be observed in Table 4.4.

Isokinetic Knee Extension

A repeated measures ANOVA revealed a significant main effect for attempt on isokinetic leg extension peak torque for FS1(p = .007), FS2 (p = .036), FS3 (p = .007), but not FS4 (p = .088). Upon further analysis, a trend emerged in the first attempt was drastically lower than the second and third attempt. Additionally, ES values comparing attempts 1 and 3 ranged from 0.31 to .55, so the first attempt was removed from the analysis indicating that systematic bias was present. Therefore, the first attempt was removed from each recovery condition for subsequent analyses.

Multiple 1-way repeated measures ANOVA comparing attempts 2 and 3 revealed no main effect for attempt on isokinetic leg extension peak torque for FS1(p = .328), FS2 (p = .193), FS3 (p = .286), and FS4 (p = .141). Visual inspection of the Q-Q plots and results of the Shapiro-Wilk tests indicated that isokinetic knee extension was normally distributed for all attempts of each recovery condition (p > .05). Mean bar velocity was reliable across all conditions. Mean values and reliability analyses for isokinetic leg extension, separated by recovery condition can be viewed in Table 4.5.

Mid-thigh Pull

Visual inspection of the Q-Q plots and results of the Shapiro-Wilk tests indicated that all attempts were normally distributed (p > .05). Results of the repeated measures ANOVAs revealed no main effect for attempt on mid-thigh pull peak torque for FS1 (p = .678), FS2 (p = .838), or FS3 (p = .291). A main effect was observed for the FS4 condition ($F_{3,27}$ = 8.18, p = .017, 1-β = .73, ηp^2 = .45) where the first attempt (2948.63 ± 680.23) was significantly higher than second attempt (2884.72 ± 678.76). However, the calculated effect size (ES = 0.09) was below the previously established threshold, so no attempts were removed from the reliability analyses. Mid-thigh pull peak force reliability metrics were found to be similar for all recovery conditions (Table 4.6).

Discussion

Studies assessing the reliability and stability of various load monitoring metrics have employed study designs to minimize participant fatigue with the assumption the biological variability within a session is not mediated by fatigue. However, when used as a metric to monitor fatigue and recovery, planned recovery time would be counterproductive to what is attempting to be measured. Fatigue increases variability of an observed score which may have a detrimental effect on the reliability and stability of a metric within an exercise session. That is, decreased reliability will increase the error around a single measure, making it less likely that the value recorded is an accurate representation of an individual's current state. From a practical perspective, monitoring metrics need to be quick and accurate so that practitioners can accurately assess the current state of an athlete without taking time from training. Therefore, the purpose of this study was to assess the impact that fatigue has on the reliability of fatigue monitoring metrics following a high-volume squatting protocol. It was hypothesized that reliability of measures would decrease as fatigue (i.e., under-recovery) increases. The SEM for countermovement jump, mean and peak bar velocity, and isokinetic leg extension peak torque reported similar SEM values regardless of the fatigue status. Interestingly, SEM values of isometric mid-thigh pull peak force continued to decrease as fatigue status increased which contradicted our hypothesis. Despite this improvement in SEM as fatigued increased, the metric itself did not appear to be sensitive to fatigue status.

Reliability analyses revealed that countermovement jump performance was stable across all recovery conditions, displaying intrasession ICC values >.9 for all conditions. While this is the first study to assess the intrasession reliability across a continuum of fatigue, previous studies have established similar findings in theoretically non-fatigued participants (Attia et al., 2017; Cormack et al., 2008; Nuzzo, Anning, & Scharfenberg, 2011; Taylor et al., 2010). For example, Cormack et al. (2008), found vertical jump height to produce comparable SEM values to the ones in the current study when assessing intra-day variability of countermovement jump height. Additionally, Nuzzo et al. (2011) found intrasession ICC values ranging from .87 to .95 and correspondingly small SEM values for countermovement jump height which appeared to be similar within a day and between days. Although the current study grouped sessions by fatigue condition, the similar ICC and SEM values between conditions indicates that countermovement jump is a stable within session metric and remains as such regardless of the current fatigue state of an individual. Additionally, MD values in comparison to the differences in means across all fatigue states suggest that countermovement jump can be used as a daily metric to monitor athletes.

However, ICC values for both mean and peak bar velocity were generally lower than any other metric, especially in the FS1 and FS2 sessions, eventually increasing by the third and fourth session. This can be explained by the purpose of ICC, as well as the bar velocity metric itself. The purpose of an ICC is to provide an index of how easy it is to differentiate between individuals, so when between-subject variability is low (i.e., homogenous) then this will have deleterious effects on the ICC. The velocity and relative load relationship is fairly stable between individuals, especially at higher loads (Sánchez-Medina, Pallarés, Pérez, Morán-Navarro, & González-Badillo, 2017). Therefore, when relative load is controlled for during the back squat, bar velocities are homogenous, making ICC values lower. There was a large degree of variability in fatigue state, as assessed by recovery scores, in the FS3 and FS4 conditions due to between-subject differences in recovery time course. This indicates that fatigue is more varied in these conditions, and consequently so too are bar velocity metrics. This increase in between-subject variability is no longer masking the measurement error, so ICC values increase. In these circumstances, Weir (2005) suggests that SEM values are instead used to understand the amount of random variability in the measure. Both mean and peak bar velocity have similar SEM values across fatigue condition, which indicates that the stability of the measure is not negatively influenced by the current fatigue status of an individual. While few studies have assessed the absolute intrasession reliability of bar velocity metrics, findings from the current study are similar to those found by (Fernandes, Lamb, & Twist, 2016) for SEM values of both peak and mean bar velocity.

Intrasession isokinetic knee extensions were found to be reliable throughout all fatigue conditions (ICC= .88 - .97). Results from the current study add to the existing literature demonstrating that peak torque during isokinetic knee extension at a speed of 180 °/s reliable in non-fatigued (Maffiuletti, Bizzini, Desbrosses, Babault, & Munzinger, 2007; Phillips, Lo, & Mastaglia, 2000; Wilhite, Cohen, & Wilhite, 1992) and fatigued state. While isokinetic knee extension peak torque was shown to be reliable, recall that the analysis was completed after removal of the first attempt due to systematic bias in which the first attempt was meaningfully lower than the second and third attempts. This trend was present during every fatigue condition which suggests that individuals had to refamiliarize themselves with the movement every day and that a single familiarization session may not allow for stable results. Indeed, multiple studies have demonstrated the effect that trial number has on precision of isokinetic dynamometer metrics due to increased systematic variability (Hill, 2014; Minshull, Gleeson, Eston, Bailey, & Rees, 2009; Sawhill, Bates, Osternig, & Hamill, 1982). For example, Habets, Staal, Tijssen, and van Cingel (2018) reported lower intrasession ICC values and higher SEM values than reported in the current study despite assessing peak torque of knee extension at 180 °/s and using the same equipment. The authors chose to calculate an ICC for absolute agreement to account for systematic differences between attempts. The lower ICC value can be explained by the fact that systematic differences were indeed present and not methodologically or statistically controlled for appropriately. Consequently, a reliability statistic, sensitive to systematic variability will be mediated when such variability is present. However, when adequate movement specific warm-up is given and individuals are able to familiarize themselves with the device as Maffiuletti et al. (2007) did, ICC calculations for absolute will yield higher ICC values. Therefore, isokinetic knee extension peak torque appears to be reliable over a continuum of fatigue, the cost of such a device and the time needed to record a stable measure may make it impractical as a metric to monitor fatigue

Peak force during the mid-thigh pull displayed excellent intrasession reliability with the lower bound of all ICC values ≥ 0.92. Contrary to our hypothesis and every other metric used in the study, reliability of the metric increased as a result of increased fatigue. Despite the intrasession reliability of the metric as demonstrated by high ICC values, the use of isometric mid-thigh pull peak force as a marker of daily monitoring may be problematic as when assessing recovery following a high-volume back squatting protocol. When examining the minimal differences needed to detect a real change in relation to the average peak force across all fatigue conditions it appears that the metric is only sensitive enough to dichotomously categorize an individual as fatigued or not fatigued, rather than being able to place an individual along a continuum. However, this appears to be due to the sensitivity of isometric mid-thigh pull to fatigue, as denoted by similar mean values across condition, rather than the reliability of the metric. The results of the current study do not contradict previous research on isometric mid-thigh pull as a metric to detect positive physiological adaptations to training (Beattie, Carson, Lyons, & Kenny, 2017) or as a surrogate marker of 1RM (De Witt et al., 2018; Wang et al., 2016).

Limitations and Future Research

While sessions were grouped by fatigue status there was also an influence of session number (i.e., baseline, 24, 48, or 72 h) on the groupings. That is, the FS1 category was comprised of all the individuals baseline performance day since they had not performed the fatiguing squat protocol yet and FS2 was comprised of the 72-h session from 10 out of the 11 participants. While a familiarization session was included to control for a learning effect, it must be considered that the session number could play a role in familiarity with a metric and the resultant reliability may be impacted. Additionally, the current study defined fatigue as a decrement in performance and participants were stratified in that manner. However, physical fatigue and recovery are defined in a variety of ways. Future research should stratify participants using different definitions of fatigue to gain a greater understanding if intrasession reliability is truly mediated by fatigue. Lastly, the current study assessed the effect of acute fatigue on reliability and while individuals will experience acute fatigue during a training program, they will also experience accumulated fatigue due to chronic training. It would be of importance to assess intrasession reliability over the course of a periodized program to see if these monitoring metrics maintain their reliability despite the assumed increase in chronic fatigue.

Conclusion

The current study is the first to assess the impact of fatigue on intrasession reliability of metrics used to monitor training adaptations. No consistent trends were observed between reliability and fatigue states for all the monitoring metrics utilized in the current study. While there were differences in SEM and ICC values across different fatigue states for an individual monitoring metric, similar values have been reported elsewhere. Therefore, it appears that the reliability of metrics used to monitor recovery are not negatively impacted by fatigue state and can be used as a daily assessment of adaptations. However, practitioners should ensure that the metric is both reliable and sensitive to changes in fatigue before using it to monitor individuals.

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Table 4.1

Descriptive Characteristics of Sample (n=11)

Metric	Mean ± SD
Age (y)	22.9 ± 3.4
Height (cm)	179.9 ± 7.8
Weight (kg)	89.9 ± 10.7
Body fat (%)	13.7 ± 4.3
BMI (kg/m^2)	27.8 ± 3.0
1RM Squat (kg)	156.5 ± 29.4

BMI, Body mass index. 1RM, 1-repetition maximum

Table 4.2

Reliability Metrics for Countermovement Jump Height Separated by Fatigue State, Ordered from Least to Most Fatigued (n=11)

	M ± SD (cm)	Reliability Assessment		
Fatigue State		SEM (cm)	ICC	MD
1	39.15 ± 4.95	1.26	0.93 (0.82-0.98)	2.92
2	35.52 ± 6.21	1.65	0.93 (0.83-0.98)	3.83
3	32.83 ± 7.20	2.00	0.92 (0.79-0.97)	4.64
4	31.16 ± 8.04	1.05	0.98 (0.95-0.99)	2.45

Notes: SEM, Standard error of measurement. ICC, intraclass correlation coefficient. MD, Minimum detectable differences

Table 4.3

Reliability Metrics for Mean Bar Velocity Separated by Fatigue State, Ordered from Least to Most Fatigued (n=11)

	M ± SD (m/s)	Reliability Assessment		
Fatigue State		SEM (m/s)	ICC	MD
1	0.67 ± 0.07	0.028	0.79 (0.55-0.93)	0.06
2	0.61 ± 0.11	0.031	0.91 (0.78-0.97)	0.07
3	0.58 ± 0.13	0.032	0.93 (0.81-0.98)	0.07
4	0.53 ± 0.15	0.032	0.93 (0.88-0.98)	0.07

Notes: SEM, Standard error of measurement. ICC, intraclass correlation coefficient. MD, Minimum detectable differences

Table 4.4

Reliability Metrics for Peak Bar Velocity Separated by Fatigue State, Ordered from Least to Most Fatigued (n=11)

	M ± SD (m/s)	Reliability Assessment		
Fatigue State		SEM (m/s)	ICC	MD
1	1.23 ± 0.15	0.053	0.84 (0.60-0.96)	0.12
2	1.10 ± 0.23	0.076	0.88 (0.71-0.96)	0.18
3	1.05 ± 0.23	0.070	0.89 (0.73-0.97)	0.16
4	1.00 ± 0.3	0.064	0.94 (0.84-0.99)	0.15

Notes: SEM, Standard error of measurement. ICC, intraclass correlation coefficient. MD, Minimum detectable differences

Table 4.5

Reliability Metrics for Isokinetic Knee Extension by Fatigue State, Ordered from Least to Most Fatigued (n=11)

Fatigue State	M ± SD (Nm)	Reliability Assessment		
		SEM (Nm)	ICC	MD
1	166.91 ± 27.04	8.759	0.88 (0.62-0.97)	20.31
2	140.27 ± 32.85	8.902	0.92 (0.73-0.98)	20.64
3	132.05 ± 31.99	5.277	0.97 (0.90-0.99)	12.24
4	124.59 ± 30.66	6.257	0.96 (0.85-0.99)	14.51

Notes: SEM, Standard error of measurement. ICC, intraclass correlation coefficient. MD, Minimum detectable differences

Table 4.6

Reliability Metrics for Isometric Mid-thigh Pull by Fatigue State, Ordered from Least to Most Fatigued (n=11)

Fatigue State	M ± SD (N)	Reliability Assessment		
		SEM (N)	ICC	MD
1	3148.8 ± 690.71	99.007	0.98 (0.92-0.99)	229.63
2	3087.6 ± 714.37	86.863	0.98 (0.95-1.00)	201.45
3	2954.88 ± 685.56	76.532	0.99 (0.95-1.00)	177.50
4	2916.68 ± 663.93	51.054	0.99 (0.98-1.00)	118.41

Notes: SEM, Standard error of measurement. ICC, intraclass correlation coefficient. MD, Minimum detectable differences

CHAPTER 5

CONCLUSION

Adequate recovery is a critical construct to assess during exercise training in order to maximize positive physiological adaptations acutely (i.e., within an exercise session or inter-set recovery) and chronically (i.e., between multiple days of exercise, over the course of days and weeks). A multitude of tools have been developed and subsequently used to assess daily recovery (e.g., performance metrics, biomarker analyses, subjective multi-item questionnaires, and heart rate variability), but these tools may be impractical for repeated and long-term use due to limitations in their speed and ease to administer, cost and accessibility, and measurement procedures (invasive technique; requires specialized equipment and/or personnel). Perceptual recovery status (PRS) is 0-10 psychophysiological scale used to assess recovery status and subsequent performance of an individual, and has shown promise as a quick, easy and sensitive tool to track recovery status. However, a paucity of research exists with PRS as a primary outcome of interest (Korak, Green, & O'Neal, 2015; Kraft et al., 2018; Laurent et al., 2011; Sikorski et al., 2013) and no study has quantified its' utility as metric to assess intrasession recovery *during* resistance exercise or directly assessed the relationship it shares with recovery of performance *following* a bout of resistance exercise. It is also critical that tools used to monitor recovery status are both valid and reliable, independent of physiological condition (i.e., fatigue status). In other words, the efficacy (or effectiveness) of the tool and its precision should not be influenced by how recovered or how fatigued one feels. While researches often utilize recovered participants to assesses the reliability of recovery metrics, this is rarely the case in an applied setting. That is, individuals use these tools throughout a continuum of recovery. No study has evaluated the impact that recovery (i.e., fatigue status) has on the reliability of non-fatiguing performance metrics. We conducted three studies to address these research gaps:

Study 1 evaluated the validity of PRS as a subjective marker of short-term recovery following a fatiguing high-volume back squatting protocol.

We hypothesized that PRS would share a strong relationship with performance metrics used to assess daily recovery, as quantified by the repeated measures correlation coefficient.

Study 2 evaluated the validity and reliability of PRS as a subjective marker of acute (inter-set) recovery during a fatiguing high-volume back squatting protocol.

We hypothesized that PRS would share strong relationships with performance metrics used to assess set quality, as quantified by the repeated measures correlation coefficient.

Study 3 investigated the influence of fatigue on the stability of performance indices assessed over 72 h of recovery following a fatiguing high-volume back squatting protocol.

We hypothesized that fatigue would be inversely associated with reliability estimates of each performance test, such that reliability estimates would be lower when assessed in a fatigued state.

Overall, the findings from our three studies suggest that PRS can be used to quantify recovery both *following* and *within* a bout of exercise. Additionally, it appeared fatigue status, induced via a high-volume squatting routine, did not mediate the stability of metrics used to assess recovery. The results from Studies 1, 2, and 3 will be discussed in greater detail in the paragraphs that follow.

The first study evaluated the validity of PRS as a subjective, daily measure of recovery 0-72h following a high-volume squatting protocol. It was revealed that PRS shared correlated strongly with countermovement jump height (r = .86), mean and peak bar velocity (r = .74 and .64; respectively), peak torque during an isokinetic knee extension (r = .61), and peak force during an isometric mid-thigh pull (r = .62). However, a sensitivity analysis revealed apparent between-subject differences in how individuals rate their recovery using PRS. Together, these findings suggest that PRS can be used daily to assess the recovery status of an individual following high-volume resistance exercise and that individual differences need to be accounted for in the application of the scale.

The second study examined the ability of PRS to detect recovery of performance between sets of a high-volume squatting protocol involving standardized rest periods. Average peak and mean bar velocity within a set, as well as the decrement in peak and mean bar velocity throughout a set of back squats correlated strongly with PRS scores (r = .55 - .67). Results suggest that PRS may be used maintain set quality throughout multiple sets of resistance exercise, although rest periods were controlled for and PRS could fluctuate in this study. Future studies should employ methodologies that allow individuals to select recovery intervals based upon a set PRS score.

The third study compared intrasession reliability of performance metrics used to monitor individuals during training through various stages of fatigue. Standard errors of the measurement (SEM) were similar across fatigue condition for countermovement jump height, mean and peak bar velocity, and peak torque during an isokinetic knee extension. However, SEM values continued to decrease as a result of fatigue for isometric mid-thigh pulls. Additionally, it was revealed that isometric mid-thigh pulls lack the sensitivity to detect daily changes in performance due to fatigue and that daily familiarization of isokinetic leg extensions is needed to control for systematic biases between attempts. Therefore, bar velocity metrics and countermovement jump performance should be used as monitoring tools because of their practicality, sustained reliability, and sensitivity to changes in performance do to fatigue.

Collectively, this dissertation demonstrates that PRS status can be used to as quick and accurate tool to monitor both daily and inter-set recovery of performance during resistance training. Additionally, the impact of fatigue on intrasession reliability was established for various load monitoring tools to determine which tools remained reliable across the continuum of fatigue in which they would be used. It has been recommended that multiple tools should be employed to monitor individuals through the course of a training period. While this dissertation has not assessed every metric that has been proposed, results from the current study suggest that PRS, countermovement jump, and bar velocity metrics can all be used to accurately assess the current fatigue state of an individual.

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APPENDIX

THE UNIVERSITY OF ALABAMA® | Office of the Vice President for Research & Economic Development
Office for Research Compliance

August 13, 2018

Michael Esco, Ph.D.
Assistant Professor
Department of Kinesiology
College of Education
The University of Alabama
Box 870312

Re: IRB Protocol # 16-021-ME-R1-B
"Heart Rate Variability for Reflecting Psychophysiology Recovery Following Physically and Mentally Stressful Events"

Dr. Esco:

The University of Alabama Medical Institutional Review Board has reviewed the revision to your previously approved full board protocol. The board has approved the change in your protocol.

Please remember that your protocol will expire on June 13, 2019.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants.

Good luck with your research.

Sincerely,

J. Grier Stewart, MD, FACP
Medical IRB Chair

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