International Journal of
EXERCISE SCIENCE

Original Research

Convergent Validity of the Short Recovery and Stress Scale in Collegiate Weightlifters

ALEC R. PERKINS†[1], KYLE S. TRAVIS‡[3], SATOSHI MIZUGUCHI‡[1], MICHAEL H. STONE‡[1], KEVIN F. BREUEL‡[2], MICHAEL KELLMANN‡[4,5], and CALEB D. BAZYLER‡[1]

[1]Center of Excellence for Sport Science and Coach Education, Department of Sport, Exercise, Recreation, and Kinesiology, East Tennessee State University, Johnson City, TN, USA; [2]ETSU Clinical Labs, Department of OB/GYN, East Tennessee State University, Johnson City, TN, USA; [3]College of Public Health and Health Professions, Department of Physical Therapy, University of Florida, Gainesville, FL, USA; [4]Unit of Sport Psychology, Faculty of Sport Science, Ruhr University Bochum, Bochum, GERMANY; [5]School of Human Movement and Nutrition Sciences, The University of Queensland, Brisbane, AUSTRALIA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 15(6): 1457-1471, 2022. The purpose of this study was to determine whether changes in collegiate weightlifters' external training load, biochemical markers, and jumping performance correlate to changes in items of the Short Recovery and Stress Scale (SRSS) throughout four microcycles. Twelve well-trained weightlifters (8 males, 4 females; age 24.30 ± 4.36 yr; height 170.28 ± 7.09 cm; body mass 81.73 ± 17.00 kg) with at least one year of competition experience participated in the study. Measurements included hydration, SRSS, biochemical analysis of blood (cortisol [C], creatine kinase [CK]), and unloaded and loaded squat jumps (SJ), and volume-load displacement. Pearson correlation coefficients were calculated between the changes in SRSS items and all other variables. The alpha criterion for all analyses was set at $p \leq 0.05$. Negative relationships were observed between changes in SRSS recovery items and C (r = -0.608 to -0.723), and unloaded and loaded SJ height and peak power (r = -0.587 to -0.636). Positive relationships were observed between changes in several SRSS stress items and C (r = 0.609 to 0.723), CK (r = 0.922), and unloaded and loaded SJ height and peak power (r = 0.583 to 0.839). Relationships between changes in some SRSS items and cortisol agree with previous findings highlighting C as an indicator of training stress. Nonetheless, the non-significant relationships between changes in SRSS items, training volume and biochemical markers disagree with previous findings. This may partly be explained by the smaller undulations in training volume in the current study, which were characteristic of typical training. Further, relationships between changes in some SRSS items and jumping performance were opposite of what was expected indicating athletes' perception of their stress and recovery state does not always correspond with their ability to perform.

KEY WORDS: Athlete monitoring, squat jump, psychological measuring, weightlifting

INTRODUCTION

The goal of developing an annual training plan and subsequent programming is to enhance athlete performance. Exercise sessions disturb homeostasis and result in acute fatigue (29). Continual training with insufficient recovery can result in accumulated fatigue (29,44). Training theory indicates that most adaptations occurs during post training session recovery/rest periods and that the final physiological/performance adaptation represent a "summary" of the stimulus-fatigue-recovery process (44). However, fatigue can mask the ability of an athlete to realize or express these adaptations (35). Thus, as fatigue subsides during recovery the athlete will be able to express accrued adaptations (29). Furthermore, the extent of adaptation can be positively or negatively affected by non-training stressors (e.g. work, school, social life, sleep) (44). The accumulation of these stressors can lead to maladaptation, and cause a plateau or a decline in performance (39,44). Continuous monitoring of stressors affecting an athlete's present state, as well as recovery from stress, can be used by coaches to detect early signs of non-functional overreaching or overtraining (44).

Investigations have examined different indicators (e.g. blood markers, jump height, rate of force development) of maladaptation in an attempt to identify those that most consistently reflect degrees of adaptation or maladaptation. Prior studies have shown that squat jump (SJ) and countermovement jump (CMJ) height are strongly correlated to weightlifting performance ($r = 0.686$, and $r = 0.642$, respectively) (46), and correspond to changes in training load (3,14). Häkkinen and colleagues (15), reported that serum cortisol concentrations in elite male weightlifters increased during stressful training and decreased significantly during reduced training. Similarly, a later study by Haff et al. (13) also reported serum cortisol concentration in national-level female weightlifters was positively related to training volume. Other researchers have examined mood state questionnaires and found that decreases in recovery scores and increased stress scores correspond with increases in training load (11,22,23) and decreases in sport related athletic performance (8). Morgan et al. (30) collected ten years of data using the Profile of Mood State (27,28) and found that mood disturbances increased with training stress; however, as training load was reduced, mood disturbances decreased back to baseline. Coutts, Wallace, and Slattery (7), examined responses in performance, physiological, biochemical and psychological indicators of overreaching in male triathletes over a six week period. The investigators found the performance test (3-km running time trial) and mood state questionnaire (RESTQ-76-Sport) were the most reliable indicators for athlete monitoring.

Taylor et al. (45) surveyed strength and conditioning coaches, sport scientists, high performance managers and head coaches of high level professional and non-professional/elite programs and found across a wide variety of sports, 84% used self-report questionnaires. Follow-up questions in the study suggest questionnaires are often chosen because of their economical and practical means for monitoring. Early questionnaires used for athlete monitoring were too long to be repeated often enough for effective monitoring and did not reflect the athlete's current recovery-stress state (32). In response to these limitations both the Acute Recovery and Stress Scale (ARSS; 26,27) and the Short Recovery and Stress Scale (SRSS; 26,27) were developed to provide a more streamlined measurement tool that measured the current recovery-stress state of the athlete. While the scales for both the ARSS and the SRSS correlated with the Recovery-Stress Questionnaire for Athletes (21) scales, and demonstrate acceptable internal consistency (Cronbach's α for ARSS [0.77 – 0.88] and SRSS [0.78 – 0.84]), the SRSS is the shortest and therefore best suited for continuous monitoring of athlete performance (24). While the SRSS has been validated with individual sport athletes such as tennis and team sport athletes such as rowing and soccer (24), strength and power athletes have not been heavily investigated. Raeder et al. (36) used the SRSS to investigate active vs. passive recovery in weightlifters; however, this study only comprised two days and included select SRSS items. Therefore, convergent validity needs to be established between physiological and performance measures and the SRSS in weightlifters over longer training periods.

Thus, the purpose of this study was to determine whether changes in collegiate weightlifters' external training load, biochemical markers, and jumping performance correlate to changes in SRSS items throughout four consecutive 7-day microcycles of their training program. We hypothesized a) changes in external training load, and biochemical markers of training stress would be positively related to changes in SRSS stress items and b) negatively related to changes in SRSS recovery items, whereas c) changes in jumping performance would exhibit positive relationships to changes in SRSS recovery items and negative relationships to changes in SRSS stress items.

METHODS

Participants

Twelve well-trained weightlifters (8 males, 4 females) with at least one year of competition experience volunteered to participate in the study (Table 1). Due to limited number of athletes on the university's Weightlifting team, no power analysis was completed to determine an adequate sample size. One athlete elected not to participate in blood draws but completed all other testing measures. The study examined athlete responses to a training program designed by the sport coaching staff to preserve ecological validity. Before data collection began, the athletes received detailed information about the purpose of the study. All participants signed an informed consent document and completed a health history questionnaire before participating in the study. The research was approved by the university's institutional review board for testing of human subjects, and was carried out in accordance with the ethical standards of the International Journal of Exercise Science (31).

Table 1. Descriptive Characteristics of Weightlifters.

Characteristics	Weightlifters (n = 12)
Age (yr)	24.30 ± 4.36
Height (cm)	170.28 ± 7.09
Body Mass (kg)	81.73 ± 17.00

Training: Weightlifters trained according to predetermined programs written by their sport coaches (Table 2). All weightlifters kept training journals as a part of regular monitoring. The study was carried out over a period of four consecutive 7-day microcycles. The first microcycle contained reduced training loads (i.e. deloading or unloading phase) to ensure athletes were recovered prior to beginning the next training cycle. During all four microcycles, the training was divided into push, pull and sport specific days. Monday and Thursday were push days. Thursday was generally lighter than the preceding Monday. Push days began with the back squat for the morning session. Additional squat, jerks and other pressing exercises were performed during the afternoon session. Wednesday was a pull day that was also broken up into a morning and afternoon session. Pull days consisted of shoulder shrugs as well as snatch and clean pull variations. Saturday was a sport specific day, similar in design to Wednesday's pull day with competition lifts in place of pull variations. Each athlete's training program was supervised by national level, weightlifting coaches.

Table 2. Example microcycle exercise selection.

Monday and Thursday	Wednesday	Saturday
AM	AM	AM
Back Squat	Snatch Tech	Snatch Tech
	CG SS	SG SS
	CG Pull	Snatch
PM	PM	Clean and Jerk
DSPS	Snatch Tech	
Split Jerk	CG SS	SG SLDL
BN Press	CG Pull - MT	SG Barbell Rows
DB Press	CG SLDL	
	CG Barbell Rows	

DSPS – Dead Stop Parallel Squat; BN – Behind Neck; DB – Dumbbell; CG – Clean Grip; SS – Shoulder Shrug; MT – Mid Thigh; SLDL – Siff-legged Deadlift; SG – Snatch Grip; Tech – Technique

Estimating Volume: Training volume completed for each training session was estimated by calculating the volume-load-displacement (9,12,42), using the following equation:

Volume-load-displacement (kg • m) = sets x repetitions x load x barbell displacement

Displacement of each exercise was measured using four linear transducers (PT101-0100-H14-1120, Celesco, Chatsworth, CA, USA) and a custom Lab View program (version 7.1, National Instruments, Austin, TX, USA) for analysis. All warm-up sets, target sets, and down sets were used to calculate volume-load-displacement (Figure 1).

Protocol

To test this hypothesis, a correlation study design was used to evaluate changes in SRSS items with changes in "commonly used" methods for monitoring weightlifters. Athletes participated in an ongoing athlete monitoring program and were familiar with the tests performed. All athletes completed a food log, in which they compiled all food and liquids they consumed in a 24-hour period, prior to the initial testing session. Athletes were then instructed to replicate this food log in the 24-hour period preceding all additional testing sessions. For each testing session, athletes were instructed to arrive at the laboratory at the same time, in a full rested and hydrated state. Athletes completed four testing sessions throughout a four microcycle period of their training program. Baseline testing (T_1) was conducted on the Saturday at the end of the first microcycle, which represented a rested state prior to beginning a new summated microcycle. Subsequently, athletes were tested prior to the first training session of the third (T_2), and fourth microcycles (T_3) with the last testing session occurring 48 hours after the final training session of the fourth microcycle (T_4), resulting in four total testing sessions. Measurements included: hydration testing, SRSS, biochemical analysis of blood followed by a standardized warm-up protocol and unloaded and loaded SJ.

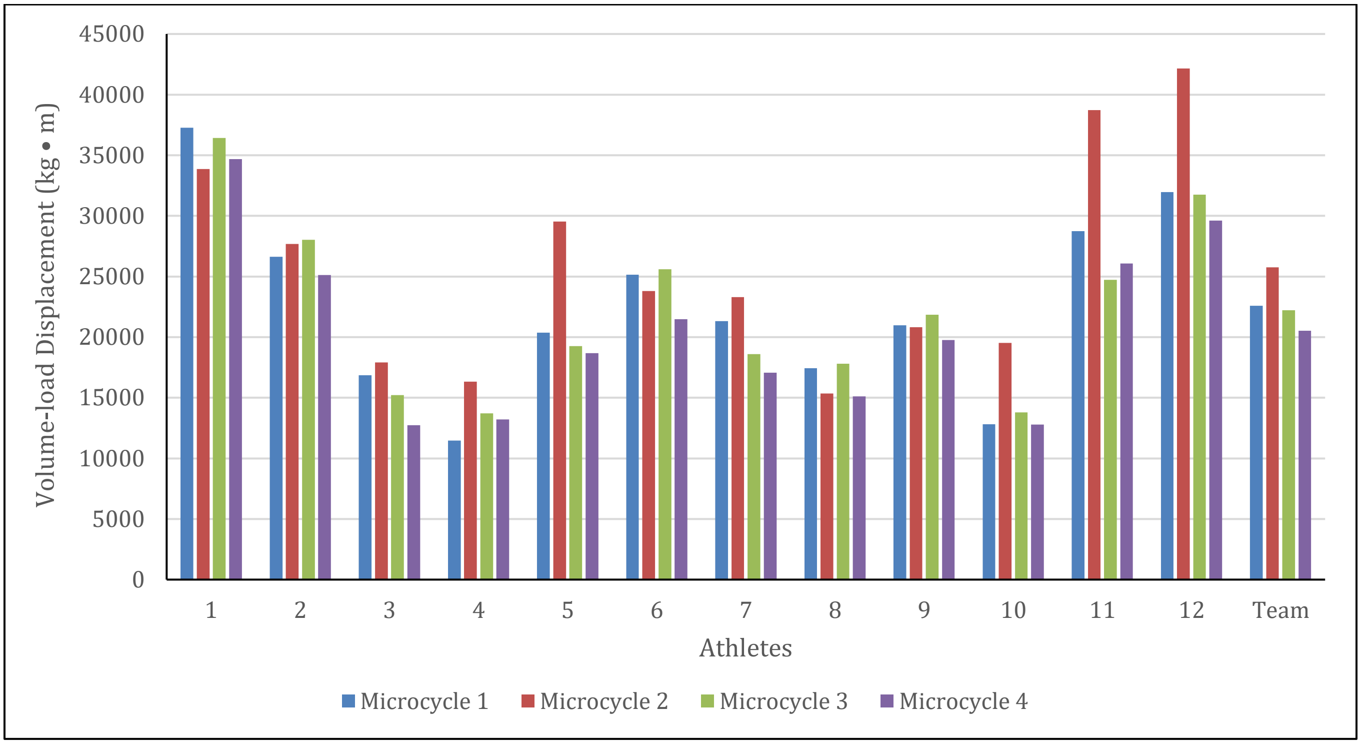

Figure 1. Volume-load-displacement for individual athletes. Team is the average volume-load-displacement of all twelve athletes.

Hydration: The hydration status was estimated using a handheld refractometer that calculates urine specific gravity on a scale ranging from 1.000 to 1.060 (Atago 4410 PAL-10S, Tokyo, Japan). If the refractometer indicated urine specific gravity was less than 1.020, the athlete passed and would continue with the testing procedure (4). If the refractometer indicated urine specific gravity was greater than or equal to 1.020, the athlete failed the test and was instructed to begin drinking water. After twenty minutes, the athlete was retested. Hydration testing continued until the athlete showed a satisfactory urine specific gravity indicating proper hydration.
Psychological Monitoring: The rating of perceived recovery and stress was determined at the start of each testing session using SRSS (24). The SRSS consists of eight items that measure the physical, mental, emotional and overall aspects of both recovery and stress. The 4 recovery items include *Physical Performance Capability* (PPC), *Mental Performance Capability* (MPC), *Emotional*

Balance (EB), *Overall Recovery* (OR); the 4 stress items include *Muscular Stress* (MS), *Lack of Activation* (LA), *Negative Emotional State* (NES), and *Overall Stress* (OS). Each item is described by a list of adjectives. The athletes were instructed to read the question and list of adjectives, then rate on a scale of 0 (does not apply at all) to 6 (fully applies) how much this applies to themselves. Numbers “1” to “5” on this scale were undefined and were used to better define the degrees of perceived recovery and stress between the two endpoints of the scale. Details of validity and reliability are reported by Kellmann and Kölling (24).

Biochemical Markers: Blood collections occurred after an overnight fast before the training session and 46-48 hours after the previous training session (between 6:15 and 7:00 am). Blood was collected from an antecubital vein and placed into a serum clot tube. Blood was allowed to clot for 20 minutes then placed in a centrifuge at 1422 x g (3400 rpm) for 15 minutes; this occurred at room temperature. Serum was then aliquoted into smaller storage tubes and stored in a -80°C freezer. Blood markers that were analysed include cortisol (C), creatine kinase (CK). These markers were measured in duplicate using an IMMULITE 1000 automated immunoassay analyser (Siemens Healthcare, Erlangen, Germany) and a solid-phase sandwich enzyme-linked immunosorbent assay (ELISA) (DSX Automated ELISA System 6.26; Dynex Technologies, Inc., Chantilly, VA, USA). The coefficient of variation for intraassay variability ranged from 0.49 to 12.3%.

Performance Test: Unloaded and loaded SJ were performed on dual uniaxial force plates with a sampling frequency of 1000 Hz (Rice Lake Weighing Systems, Rice Lake, WI, USA); the plates were embedded, side by side, into a 2.44m x 2.44m custom built plywood platform. Athletes began by stepping on the force plates with either a near weightless polyvinyl chloride (PVC) pipe (<1 kg) or 20kg barbell across their shoulders to prevent arm swing. The athlete was then instructed to perform a squat to a knee angle of 90° (measured using a handheld goniometer) and maintain this static position until the force-time trace was stable (5). Once the force-time trace was stable, the test administrator shouted “3,2,1...jump!” and the athlete performed a SJ. Maximal effort squat jumps were preceded by warm-up SJ’s at 50% and 75% perceived effort. The athlete performed maximal effort SJ’s until two trials were recorded with a difference of < 2 cm. All jump trials were recorded and analysed using a custom-built analysis program (Lab View 2010, National Instruments Co., Austin, TX, USA). Squat jump height (SJH) was estimated from flight time (26). Peak power was determined as the maximal value obtained from the product of force-time trace and derived velocity-time trace during the concentric phase of the jump. Peak power was allometrically scaled (PPa) to the weightlifter’s body mass. Test-retest reliability has been established in our laboratory for JH (ICC = 0.93 to 0.99, CV = 2.08 to 7.32%) and PPa (ICC = 0.95 to 0.98, CV = 2.20 to 2.31%) (1,2).

Statistical Analysis

In order to examine the relationship between SRSS and blood markers in response to different training loads, correlations were performed on the change scores between time points rather than raw values for each time point. After the data set was scanned for outliers (cut-off: mean ±

3 SD), normality was assessed using the Shapiro–Wilk test. Pearson correlation coefficients with 90% confidence intervals (CI) were calculated between the change in SRSS scores and all other variables from T_1 - T_2, T_1 - T_3, and T_1 - T_4. A Holm's sequential Bonferroni procedure was used to control Type I error inflation (19). Correlation coefficients were evaluated using the following scale: 0.0 – < 0.1 trivial, 0.1 – < 0.3 weak, 0.3 – < 0.5 moderate, 0.5 – < 0.7 strong, 0.7 – < 0.9 very strong, 0.9 – < 1 nearly perfect (20). The alpha criterion for all analyses was set at $p \leq 0.05$. Statistics Package for Social Sciences version 23 (IBM Co., Armonk, NY, USA) and Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) were used to perform all statistical analyses.

RESULTS

Statistically significant negative relationships were observed between the PPC item and C from T_1 to T_2 (r = -0.723, p = 0.012) (Table 3, Table 4, Figure 2) and from T_1 to T_3 (r = -0.679, p = 0.022). A statistically significant negative relationship was observed between the MPC item and C from T_1 to T_2 (r = -0.634, p = 0.036). A statistically significant negative relationship was observed between the OR item and C from T_1 to T_2 (r = -0.608, p = 0.047). Statistically significant positive relationships were observed between the LA item and C from T_1 to T_2 (r = 0.609, p = 0.047), from T_1 to T_3 (r = 0.723, p = 0.05) (Figure 3) and from T_1 to T_4 (r = 0.660, p = 0.027). A statistically significant positive relationship was observed between the NES item and CK from T_1 to T_2 (r = 0.922, p < 0.001). No other statistically significant relationships were observed between changes in SRSS items and volume-load-displacement, C, or CK.

Table 3. Changes in dependent variables.

	Mean ± SD			
	T_1	T_2	T_3	T_4
Jumping Performance				
JH 0kg (cm)	34.53±7.47	34.11±6.75	34.04±7.24	35.51±7.24
PPa 0kg (W ·kg$^{-0.67}$)	251.18±49.54	250.29±47.83	246.43±47.09	254.38±50.10
JH 20kg (cm)	26.78±6.49	26.71±6.19	26.74±6.38	27.75±6.84
PPa 20kg (W ·kg$^{-0.67}$)	246.79±49.53	248.07±46.18	245.35±46.89	248.39±47.13
Blood Markers				
C	14.83±5.00	17.24±4.85	17.85±4.01	17.17±2.76
CK	175.36±102.10	441.73±532.42	251.09±269.71	216.00±169.80
SRSS				
PPC	4.50±0.90	4.25±1.06	4.08±1.44	4.50±1.17
MPC	4.00±1.21	3.67±1.44	3.92±1.24	3.83±1.19
EB	4.33±1.37	4.50±1.31	3.58±1.38	4.08±1.24
OR	3.92±1.08	4.33±1.50	4.08±1.24	4.17±0.94
MS	2.08±1.24	1.50±1.17	1.50±1.17	1.75±1.06
LA	2.67±1.67	2.50±1.57	2.33±1.87	2.25±1.14
NES	1.33±1.23	1.58±1.68	1.92±1.51	1.50±1.24
OS	1.67±0.98	2.17±0.83	2.33±1.07	2.08±1.51

SD - Standard deviation, JH - Squat jump height, PPa - Peak power allometrically scaled for body mass, C – Cortisol; CK – Creatine kinase, PPC - *Physical Performance Capability*, MPC - *Mental Performance Capability*, EB - *Emotional Balance*, OR - *Overall Recovery*, MS - *Muscular Stress*, LA - *Lack of Activation*, NES - *Negative Emotional State*, OS - *Overall Stress*

A statistically significant positive relationship was observed between the MS item and unloaded PPa from T_1 to T_2 (r = 0.615, p = 0.033). A statistically significant negative relationship was observed between the EB item and unloaded PPa from T_1 to T_3 (r = -0.636, p = 0.026). A statistically significant positive relationship was observed between the OS item and unloaded PPa from T_1 to T_3 (r = 0.601, p = 0.039). A statistically significant negative relationship was observed between the PPC item and loaded PPa from T_1 to T_2 (r = -0.587, p = 0.045). A statistically significant positive relationship was observed between the OS item and loaded PPa from T_1 to T_3 (r = 0.647, p = 0.023). A statistically significant positive relationship was observed between the LA item and unloaded JH from T_1 to T_4 (r = 0.602, p = 0.038). Statistically significant positive relationships were observed between the MS item and loaded JH from T_1 to T_2 (r = 0.839, p < 0.001) (Figure 4) and from T_1 to T_4 (r = 0.583, p = 0.046). A statistically significant negative relationship was observed between the PPC item and loaded JH from T_1 to T_2 (r = -0.626, p = 0.029). A statistically significant positive relationship was observed between the NES item and loaded JH from T_1 to T_3 (r = 0.631, p = 0.028). No other statistically significant relationships were observed between changes in SRSS items and SJ measures.

Table 4. Significant correlations between SRSS items and other measures.

	r [90% CI]		
	ΔT_1 to T_2	**ΔT_1 to T_3**	**ΔT_1 to T_4**
PPC v C	-0.723 [-0.321,-0.904]	-0.679 [-0.241,-0.887]	
PPC v JH20kg	-0.626 [-0.184,-0.857]		
PPC v PPa20kg	-0.587 [-0.124,-0.84]		
LA v C	0.609 [0.125,0.859]	0.723 [0.321,0.904]	0.66 [0.208,0.88]
LA v JH0kg			0.602 [0.147,0.847]
MS v JH20kg	0.839 [0.585,0.943]		0.583 [0.118,0.838]
MS v PPa0kg	0.615 [0.167,0.852]		
OS v PPa0kg		0.601 [0.145,0.846]	
OS v PPa20kg		0.647 [0.218,0.866]	
NES v CK	0.922 [0.77,0.975]		
NES v JH20kg		0.631 [0.192,0.859]	
OR v C	-0.608 [-0.124,-0.858]		
EB v PPa0kg		-0.636 [-0.2,-0.862]	
MPC v C	-0.634 [-0.165,-0.869]		

C – Cortisol; CK – Creatine kinase; JH – Jump height; PPa – Peak power allometrically scaled; PPC – *Physical Performance Capability*; MPC – *Mental Performance Capability*; EB – *Emotional Balance*; OR – *Overall Recovery*; MS – *Muscular Stress*; LA – *Lack of Activation*; NES – *Negative Emotional State*; OS – *Overall Stress*

DISCUSSION

The purpose of this study was to determine whether changes in collegiate weightlifters' biochemical markers, SJ performance and external training load correlate to changes in SRSS recovery and stress items. Our hypothesis was only partly supported by the results of this investigation. Biochemical markers of training stress were positively related to stress items, and negatively related to recovery items as expected; however, correlations between SRSS items and jumping performance were consistently opposite of what was expected.

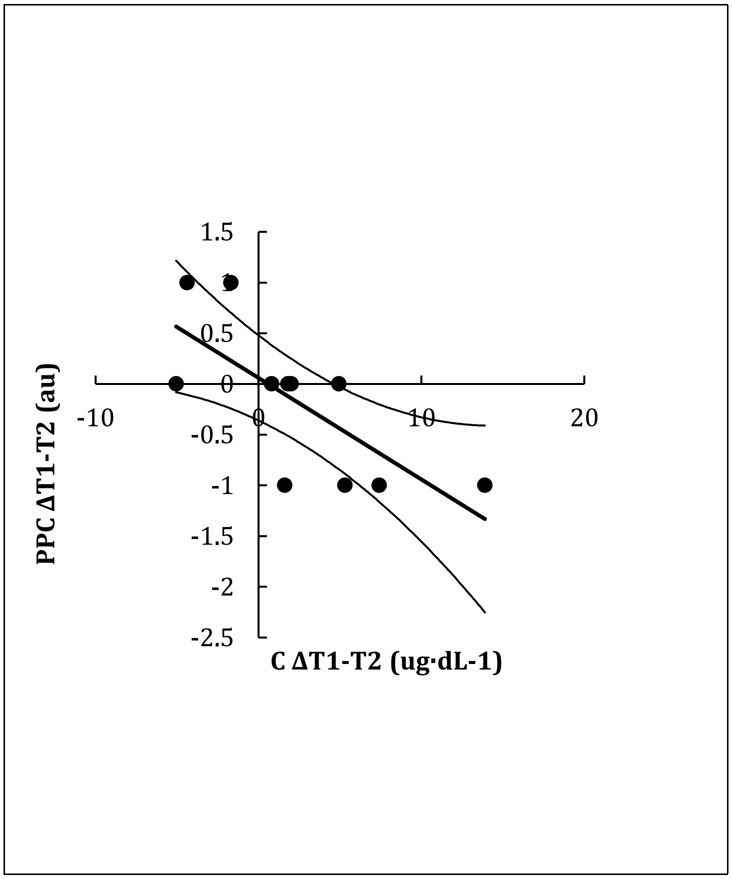

Figure 2. Relationship between changes in C and changes in PPC (r = -0.723, p = 0.012). This figure includes eleven (n = 11) weightlifters; C = Cortisol, PPC = *Physical Performance Capability*.

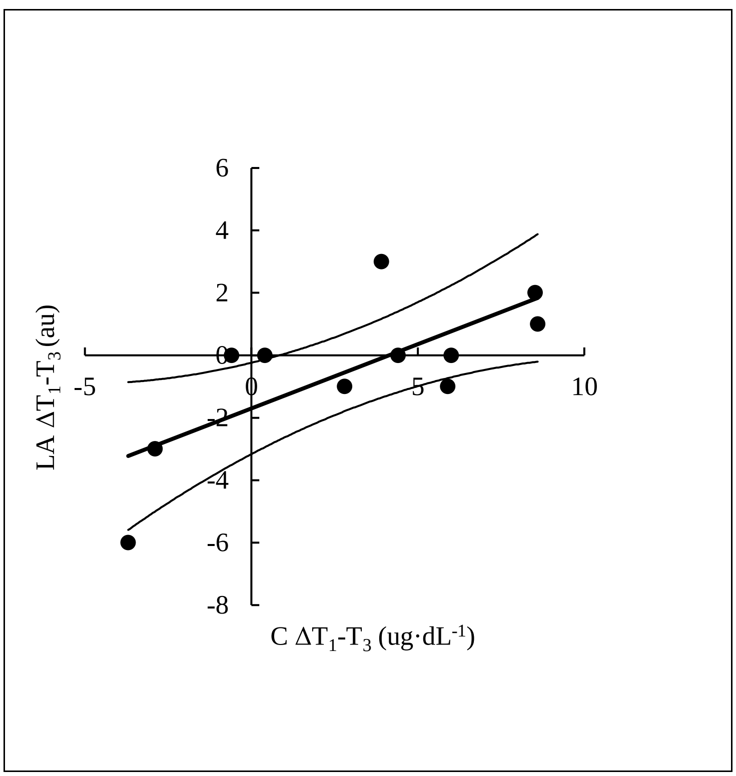

Figure 3. Relationship between changes C and changes in LA (r = 0.723, p = 0.05). This figure includes eleven (n = 11) weightlifters; C = cortisol, LA = *Lack of Activation*.

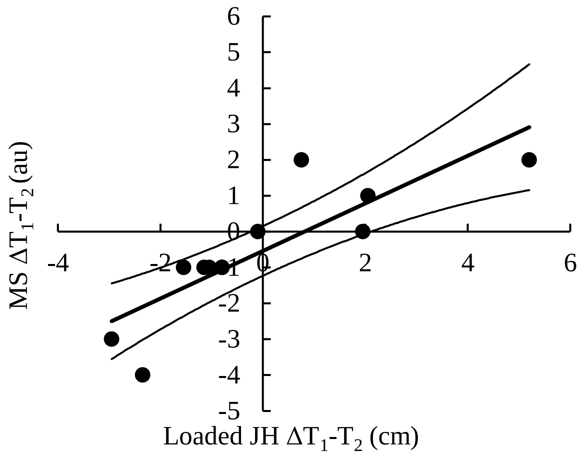

Figure 4. Relationship between changes in loaded JH and changes in MS (r = 0.839, p < 0.001). This figure includes twelve (n = 12) weightlifters; JH = Jump height, MS = *Muscular Stress*.

Previous investigations have shown resting C concentrations to rise during periods of high training volume and decrease during periods of reduced training volume (10,13,15,38). In the current investigation, changes in C did not correlate with changes in volume-load-displacement; however, changes in C did correlate with changes in several SRSS recovery and stress items. Recovery items PPC, MPC and OR were negatively correlated with C concentrations, while the stress item LA was positively correlated with C concentrations. A greater number of SRSS recovery items correlated with C concentrations compared to stress items, which seem to reflect previous findings by Wiewelhove et al. (48), who found greater changes in recovery items than stress items following a "shock" microcycle. The recovery item PPC and the stress item LA were the only two SRSS items to correlate with C across multiple time points. The relationships between C and PPC were expected, as this recovery item is more sensitive to changes in training stress, whereas LA is more responsive to long-term factors of training stress (24).

Increases in CK concentrations has been shown to mirror mechanical-muscular strain from preceding days of exercise (47). This relationship has made increases in CK a commonly accepted marker of structural damage to muscle fibres. Our results found a near perfect positive correlation between CK and the SRSS stress item NES. This result is in agreement with previous research demonstrating increases in SRSS stress items coincide with an increase in resting CK levels (18,37,48). It should be noted that the correlation between CK and NES occurred during transitioning between summated microcycles. Training programs observed during this investigation used a periodization strategy known as phase potentiation (40,41). This strategy is applied within the summated microcycles themselves, each emphasising either one or multiple fitness characteristics (strength-endurance, strength, power, speed, etc.), and organized in such a way that adaptions from one summated microcycle potentiate adaptations in the subsequent summated microcycle. This change in emphasis occurs concomitantly with changes in set and repetition scheme, relative intensity, and is accompanied by changes in exercise selection. It appears this alteration in training stimuli resulted in an increased resting CK concentration that the SRSS was also able to detect.

Vertical jumps are a commonly used performance measure to evaluate general athletic ability (6,17,33,34,43,45). Specifically, SJ height and peak power exhibit moderate to strong correlation to weightlifting performance (3,46). In the current investigation, all correlations between changes in SJ performance and several recovery items (PPC and EB) and stress items (MS, LA, NES, OS) were the opposite of what was expected. Prior studies incorporating SRSS and countermovement jumps found jumping performance decreased with SRSS recovery items during intensified training, while stress items increased (18,37). Following three days of training cessation, CMJ's and SRSS items returned to baseline. The results in the present study indicate that an athlete's perception of their stress and recovery state does not always correspond with their ability to perform. While this disconnection between SJ performance and SRSS items may conflict with previous research, it indicates athlete monitoring should not be based upon athlete perception alone, but comprehensively from a multi-dimensional monitoring program (16).

No significant correlations were found between changes in volume-load-displacement and changes in SRSS stress or recovery items. These finding are in disagreement with previous studies showing a positive relationship between increases in training volume and SRSS stress items and a negative relationship with SRSS recovery items (18,37,48). This discrepancy may partly be explained by the smaller undulations in volume-load-displacement in the current study, which are more characteristic of typical training. Several prior investigations that incorporated the SRSS into their testing protocols, used a six-day intensified microcycle to intentionally cause overreaching. The intensified microcycle was preceded by a four-day rest period during which no training or fatiguing exercise was allowed. This four-day period of inactivity would give athletes ample time to significantly reduce accumulated fatigue from their regular training prior to the testing protocol. Correspondingly, in these same investigations most measures of fatigue had returned to baseline following the three day recovery period in which again no training was allowed (18,37). During our observation, volume-load-displacement increased 14.0% from microcycle 1 to 2 and decreased 9.1% from microcycle 1 to 4. These minor changes in volume-load-displacement did not appear to be great enough to cause corresponding changes in SRSS items.

There are two limitations that should be considered when evaluating the results of this study. First, the study was observational, and as a result the study staff could not control or manipulate any variables over the course of the four microcycles. The second limitation was the small sample size, although this was unavoidable as all weightlifters on the team agreed to participate. Future research should examine the agreement between SRSS, physiological, and performance measures in weightlifters during phases with larger training load undulations (e.g. strength-endurance, overreach, taper) to determine whether similar relationships exist.

In conclusion, the results of this study partly support the convergent validity of the SRSS in weightlifters. Relationships between changes in some SRSS items, CK, and C agree with previous findings, highlighting both as a strong indicator of training stress. Nonetheless, the non-significant relationships between changes in SRSS items, training volume and biochemical markers disagree with previous findings. This may partly be explained by the smaller undulations in training volume in the current study, which were characteristic of typical training. Further, relationships between changes in some SRSS items and jumping performance were opposite of what was expected indicating athlete's perception of their stress and recovery state did not always correspond with their ability to perform. Therefore, weightlifting coaches should be cautious in using results from a single test to estimate an athlete's preparedness. We recommend the SRSS be included as part of a multi-dimensional monitoring program for weightlifters.

REFERENCES

1. Bazyler CD, Mizuguchi S, Kavanaugh AA, McMahon JJ, Comfort P, Stone MH. Returners exhibit greater jumping performance improvements during a peaking phase compared with new players on a volleyball team. Int J Sports Physiol Perform 13(6): 709–716, 2018.

2. Bazyler CD, Mizuguchi S, Sole CJ, Suchomel TJ, Sato K, Kavanaugh AA. Jumping performance is preserved but not muscle thickness in collegiate volleyball players after a taper. J Strength Cond Res 32(4): 1020–1028, 2018.

3. Carlock JM, Smith SL, Hartman MJ, Morris RT, Ciroslan DA, Pierce KC. The relationship between vertical jump power estimates and weightlifting ability: a field-test approach. J Strength Cond Res 18(3): 534–539, 2004.

4. Casa DJ, Clarkson PM, Roberts WO. American College of Sports Medicine roundtable on hydration and physical activity: consensus statements. Current Sports Med Rep 4(3): 115–127, 2005.

5. Cavagna GA, Saibene FP, Margaria R. Effect of negative work on the amount of positive work performed by an isolated muscle. J Appl Physiol 20(1): 157–158, 1965.

6. Chelly MS, Fathloun M, Cherif N, Amar MB, Tabka Z, Van Praagh E. Effects of a back squat training program on leg power, jump, and sprint performances in junior soccer players. J Strength Cond Res 23(8): 2241–2249, 2009.

7. Coutts A, Wallace L, Slattery K. Monitoring changes in performance, physiology, biochemistry, and psychology during overreaching and recovery in triathletes. Int J Sports Med 28(2): 125–134, 2007.

8. Coutts AJ, Reaburn P. Monitoring changes in rugby league players' perceived stress and recovery during intensified training. Percept Mot Skills 106(3): 904–916, 2008.

9. DeWeese BH, Hornsby G, Stone M, Stone MH. The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. J Sport Health Sci 4(4): 308–317, 2015.

10. Fry AC, Kraemer WJ, Gordon SE, Stone MH, Warren BJ, Fleck SJ. Endocrine responses to overreaching before and after 1 year of weightlifting. Can J Appl Physiol 19(4): 400–10, 1994.

11. González-Boto R, Salguero A, Tuero C, González-Gallego J, Márquez S. Monitoring the effects of training load changes on stress and recovery in swimmers. J Physiol Biochem 64(1): 19–26, 2008.

12. Haff GG. Quantifying workloads in resistance training: A brief review. Prof Strength Cond 19: 31–40, 2010.

13. Haff GG, Jackson JR, Kawamori N, Carlock JM, Hartman MJ, Kilgore JL. Force-time curve characteristics and hormonal alterations during an eleven-week training period in elite women weightlifters. J Strength Cond Res 22(2): 433–446, 2008.

14. Häkkinen K, Komi PV, Kauhanen H. Electromyographic and force production characteristics of leg extensor muscles of elite weight lifters during isometric, concentric, and various stretch-shortening cycle exercises. Int J Sports Med 7(3): 144–151, 1986.

15. Häkkinen K, Pakarinen A, Alen M, Kauhanen H, Komi PV. Relationships between training volume, physical performance capacity, and serum hormone concentrations during prolonged training in elite weight lifters. Int J Sports Med 8: 61–65, 1987.

16. Halson SL. Monitoring training load to understand fatigue in athletes. Sport Med 44(2): 139–147, 2014.

17. Hartman MJ, Clark B, Bemben DA, Kilgore JL, Bemben MG. Comparisons between twice-daily and once-daily training sessions in male weight lifters. Int J Sports Physiol Perform 2(2): 159–169, 2007.

18. Hitzschke B, Wiewelhove T, Raeder C, Ferrauti A, Meyer T, Pfeiffer M. Evaluation of psychological measures for the assessment of recovery and stress during a shock-microcycle in strength and high-intensity interval training. Perform Enhanc Health 5(4): 147–157, 2017.

19. Holm S. A simple sequentially rejective multiple test procedure. Scand J Statist 6: 65–70, 1979.

20. Hopkins WG. A scaled of magnitudes for effect statistics [Internet]. A new view of statistics., 2002.

21. Kallus KW, Kellmann M. The Recovery-Stress Questionnaire for Athletes. In: The Recovery-Stress Questionnaire: User Manual. Kallus KW, Kellmann M, eds. . Frankfurt am Main: Pearson Assessment & Information GmbH., 2016.

22. Kellmann M, Altenburg D, Lormes W, Steinacker JM. Assessing stress and recovery during preparation for the world championships in rowing. Sport Psychol 15(2): 151–167, 2001.

23. Kellmann M, Günther K-D. Changes in stress and recovery in elite rowers during preparation for the Olympic Games. Med Sci Sports Exerc 32(3): 676–683, 2000.

24. Kellmann M, Kölling S. Recovery and stress in sport: A manual for testing and assessment. Abington: Routledge, 2019.

25. Kellmann M, Kölling S, Hitzschke B. Das Akutmaß und die Kurzskala zur Erfassung von Erholung und Beanspruchung im Sport - Manual [The Acute Measure and the Short Scale of Recovery and Stress for Sports - Manual]. Hellenthal: Sportverlag Strauß, 2016.

26. Linthorne NP. Analysis of standing vertical jumps using a force platform. Am J Phys 69(11): 1198–1204, 2001.

27. McNair DM, Lorr M, Droppleman LF. Profile of Mood States manual. San Diego, CA: Educational & Industrial Testing Service, 1971.

28. McNair DM, Lorr M, Droppleman LF. Profile of Mood States manual. San Diego, CA: Educational & Industrial Testing Service, 1992.

29. Meeusen R, Duclos M, Foster C, Fry A, Gleeson M, Nieman D, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. Med Sci Sports Exerc 45(1): 186–205, 2013.

30. Morgan WP, Brown DR, Raglin JS, O'Connor PJ, Ellickson KA. Psychological monitoring of overtraining and staleness. Br J Sports Med 21(3): 107–114, 1987.

31. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

32. Nicolas M, Vacher P, Martinent G, Mourot L. Monitoring stress and recovery states: Structural and external stages of the short version of the RESTQ sport in elite swimmers before championships. J Sport Health Sci 8(1): 77–88, 2019.

33. Nuzzo JL, McBride JM, Cormie P, McCaulley GO. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. J Strength Cond Res 22(3): 699–707, 2008.

34. Ostojić SM, Stojanović M, Ahmetović Z. Vertical jump as a tool in assessment of muscular power and anaerobic performance. Med Pregl 63(5–6): 371–375, 2010.

35. Plisk SS, Stone MH. Periodization strategies. Strength Cond J 25(6): 19–37, 2003.

36. Raeder C, Wiewelhove T, Schneider C, Döweling A, Kellman M, Meyer T. Effects of active recovery on muscle function following high-intensity training sessions in elite Olympic weightlifters. Adv Skelet Muscle Funct Assess 1(1): 3–12, 2017.

37. Raeder C, Wiewelhove T, Simola RÁDP, Kellmann M, Meyer T, Pfeiffer M. Assessment of fatigue and recovery in male and female athletes after 6 days of intensified strength training. J Strength Cond Res 30(12): 3412–3427, 2016.

38. Stone MH, Fry AC. Increased training volume in strength/power athletes. In: Overtraining in Sport. Kreider RB, Fry AC, O'Toole ML, eds. Human Kinetics, 1998.

39. Stone MH, Keith RE, Kearney JT, Fleck SJ, Wilson GD, Triplett NT. Overtraining: A review of the signs, symptoms and possible causes. J Strength Cond Res 5(1): 35, 1991.

40. Stone MH, O'Bryant H, Garhammer J. A hypothetical model for strength training. J Sports Med Phys Fitness 21(4): 342, 1981.

41. Stone MH, O'Bryant H, Garhammer J, McMillan J, Rozenek R. A theoretical model of strength training. Natl Strength Cond Assoc J 4(4): 36–39, 1982.

42. Stone MH, Pierce K, Godsen R, Wilson GD, Blessing D, Rozenek R. Heart rate and lactate levels during weight-training exercise in trained and untrained men. Phys Sportsmed 15(5): 97–105, 1987.

43. Stone MH, Sanborn KIM, O'Bryant H, Hartman MJ, Stone ME, Proulx C, et al. Maximum strength-power-performance relationships in collegiate throwers. J Strength Cond Res 17(4): 739–745, 2003.

44. Stone MH, Stone M, Sands WA. Principles and practice of resistance training. Champaign, IL: Human Kinetics, 2007.

45. Taylor K, Chapman D, Cronin J, Newton MJ, Gill N. Fatigue monitoring in high performance sport: a survey of current trends. J Aust Strength Cond 20(1): 12–23, 2012.

46. Travis SK, Goodin JR, Beckham GK, Bazyler CD. Identifying a test to monitor weightlifting performance in competitive male and female weightlifters. Sports 6(2): 46, 2018.

47. Urhausen A, Kindermann W. Diagnosis of overtraining. Sports Med 32(2): 95–102, 2002.

48. Wiewelhove T, Raeder C, Meyer T, Kellmann M, Pfeiffer M, Ferrauti A. Effect of repeated active recovery during a high-intensity interval-training shock microcycle on markers of fatigue. Int J Sports Physiol Perform 11(8): 1060–1066, 2016.