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Reproducibility of Objective and Subjective Markers of Exercise Recovery in College Aged Males

KATIE COFFEY*, RACHEL MCCOLLUM*, ELIZABETH SMYTH*, ELIZA CASEY*, JADE PLUNKETT*, and KATY HORNER‡

School of Public Health, Physiotherapy, and Sport Science and Institute for Sport and Health, University College, Dublin, IRELAND

*Denotes undergraduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(4): 1041-1051, 2020. This study investigated the reproducibility of objective and subjective parameters of recovery pre- and post-exercise in college-aged male athletes. Thirteen male (aged 19-22y) team sport players were assessed for a range of recovery markers before and 24 hours after a repeated sprint protocol. An identical procedure was followed one week later. Participants undertook two objective tests: creatine kinase (CK) and countermovement jump (CMJ) height; and two subjective tests: visual analogue scale (VAS) for muscle soreness and 5-item well-being questionnaire (WB). Coefficients of variation (CV) of CMJ and WB were lowest of all markers studied both pre (4.0% and 5.9%) and 24 hours post (7.7% and 7.1%) exercise, respectively. The CV of a single CMJ showed the highest reproducibility pre-exercise (4.0%) compared to taking the best or average of 2 or 3 jumps. Both CK and VAS had a high CV at pre (25.6% and 49.2%) and 24 hours post (44.5% and 44.8%) exercise. Moreover, while there was no difference between the change in CMJ, WB and VAS in response to exercise between weeks, the increase in CK was greater after the first compared to second exercise bout (mean 199.6 U/L vs 10.6 U/L change, $p = 0.001$), indicating a repeated bout effect. CK and VAS demonstrated poor reproducibility. However, single CMJ height and the WB questionnaire demonstrated a high reproducibility pre- and post-exercise and represent simple time-efficient objective and subjective methods to monitor recovery in this population.

KEY WORDS: Countermovement jump, muscle damage, monitoring, muscle soreness, self-report, sprint interval training, wellbeing

INTRODUCTION

Knowledge of the reproducibility of markers of exercise recovery is essential to understand the physiological relevance of any changes if observed (e.g., in response to an intervention or during a season). The reproducibility of a range of markers of exercise recovery has previously been well studied under resting conditions, with participants instructed to avoid exercise for a number of days beforehand or during off-season (e.g., Roe et al. (24)). However, understanding of the reproducibility of these measures in post-exercise conditions is also important as these measures are often used to investigate the efficacy of different exercise recovery protocols such as nutrition or other recovery interventions.

Although less information exists on the reproducibility of common recovery markers in post-exercise conditions, there is some evidence that the variability may differ post-exercise (11, 25). Russell et al. (25) assessed the variability of peak power output during a countermovement jump (CMJ) along with creatine kinase (CK) concentrations pre, 24 hours and 48 hours post-match over 1-4 matches in 14 soccer players. The coefficient of variation (CV) for the CMJ was similar (~10-11%) pre, 24- and 48-hours post-match, whereas for CK the variability was much higher, particularly at baseline with CV's of ~42, 30 and 34% for pre, 24- and 48-hours post-match respectively. Others (21) have assessed recovery responses to two identical Loughborough intermittent shuttle tests 14 days apart in 8 well trained team sport athletes, finding muscle soreness was rated lower following the second bout, but there were no differences in any other markers between the two bouts including CMJ and CK. These data highlight that the reproducibility of objective and subjective responses to exercise might differ. However, reproducibility statistics were not reported.

Repeated sprints are frequently undertaken in training in several sports, and have been increasingly used to elicit exercise induced muscle damage in studies examining the efficacy of different recovery interventions including in college-aged athletes (e.g., (6, 19)). Some studies use independent study designs to avoid any potential repeated bout effect (6), whereas others have used repeated measures designs (30). Knowledge of the variability of responses to an identical bout of repeated sprint exercise is therefore key for optimizing study design and interpreting findings.

The best outcomes to use to monitor recovery have also been widely debated. For the CMJ, although a 'best of 3' approach has been most commonly taken when assessing outcomes, a recent meta-analysis has questioned this, finding average jump height to be more sensitive (5). The reproducibility of the different approaches warrant further study, given previous studies have primarily focused on a 'best of 3' approach (11, 24). Moreover, the use of subjective measures to complement objective markers has been emphasized for player monitoring (26), however the reproducibility of subjective markers has generally been less well studied.

The aims of the present study were therefore to investigate the reproducibility of commonly used objective (CMJ height and CK) and subjective (muscle soreness and wellbeing) markers of recovery both prior to and 24 hours following two identical bouts of repeated sprint exercise one week apart in college aged male athletes.

METHODS

Participants

Seventeen healthy, male college athletes volunteered and thirteen (age: 20.8 ± 0.7 years, weight: 80.1 ± 7.4 kg, height: 180.7 ± 6.3 cm and body mass index 25 ± 1.9 kg/m^2) completed this study. A sample size of 10 participants is sufficient to detect a significant change in indirect markers of muscle damage at 80% power and alpha level of 0.05 (10). Inclusion criteria were male aged 18-30, participating in team sport, training at least twice per week, with no lower limb injury in the past 6 months and no known medical conditions. Participants reported undertaking a variety of sports including rugby, soccer, GAA and tag rugby, and continued their normal training with the exception of avoiding exercise 24 hours prior to pre-exercise testing until completion of the second testing day, on both weeks. The study was conducted according to the guidelines laid down in the Declaration of Helsinki. Following institutional ethical approval, all participants were provided with a participant information sheet before giving informed consent. This research was carried according to the ethical standards of the International Journal of Exercise Science (23).

Protocol

Participants completed two identical exercise bouts one week apart, with measurements taken prior to and 24 hours post exercise on both occasions. Outcome measures included CK, CMJ jump height, VAS for muscle soreness and WB.

The exercise protocol involved participants first completing a warm up, including 200m of self-selected jogging pace, followed by a dynamic stretching routine. An identical warm up was replicated the following week. The exercise protocol was adapted from that used by others (17), and designed to include sprint lengths and recovery times observed in different sports (27). The repeated sprint protocol consisted of 15 maximal effort 30m sprints, with a change of direction at 15m, combined with 30 second rest periods between sprints. A 5m deceleration zone was marked out at the end of each 30m sprint, where participants were asked to slow down and come to a stop at the final marker. Standardised verbal encouragement was used throughout each sprint. All testing took place outdoors on a grass pitch. Following each sprint, participants were shown a Borg scale to assess rate of perceived exertion (RPE) (2). Participants were given a count down at the beginning of the repeated sprints and as each rest period was ending (3,2,1 – Go).

Whole-blood CK was assessed from a 30ul fingertip capillary sample that was immediately analysed using reflectance photometry (Reflotron Plus; Roche Diagnostics GmbH, Mannheim, Germany). Quality control measurements were undertaken using standardised CK strips. The published reliability of the CK strips using this method is a CV <2% for whole blood (15).

Countermovement jumps were performed on a portable force plate (HUR labs, Tampere, Finland). Participants were first given a demonstration of a CMJ with the standardised protocol requiring hands to be kept on hips throughout the jump (8). Participants then undertook one familiarisation jump followed by three maximal effort CMJs. Jump height was the outcome measure used, with the highest value from the three jumps taken as the main outcome. Additionally, the first jump height, the highest of the first two jumps, and the average of two and three jumps were analysed.

A 200mm Visual Analogue Scale (VAS) was completed to determine muscle soreness in the lower limb. Participants were asked to squat at a knee angle of approximately 90 degrees while ensuring their hands stayed on their hips, and subsequently place a mark on the scale which included 'no soreness' at one end and 'unbearable pain' at the other.

A 5-item well-being questionnaire as previously used by others (22, 24) was completed to assess participant's fatigue, sleep quality, general muscle soreness, stress levels and mood on a five-point scale. Each section received a score between 1 and 5, and overall well-being was determined by summing the five scores.

Statistical Analysis

The intra-individual CV and intra-class correlation coefficient (ICC) were used to analyse the reproducibility of the parameters for each time point, using Microsoft EXCEL, with a published spreadsheet used to determine ICCs (14). Smallest worthwhile change (SWC) was calculated as described previously (24). Responses to the exercise bout in week 1 and week 2 were also examined by comparing change scores (post-pre exercise) between the two weeks using paired t-tests for CK, CMJ and WB and using Wilcoxon signed rank test for VAS and RPE. Analysis was conducted using SPSS (version 21.0; IBM, NY, USA) and GraphPad Prism (for Mac, version 8). Significance was accepted at $p < 0.05$.

RESULTS

Results are reported for participants ($n = 13$) who completed all testing sessions. There were no significant differences in RPE values at each sprint between the two weeks (Figure 1, $p > 0.05$ for all).

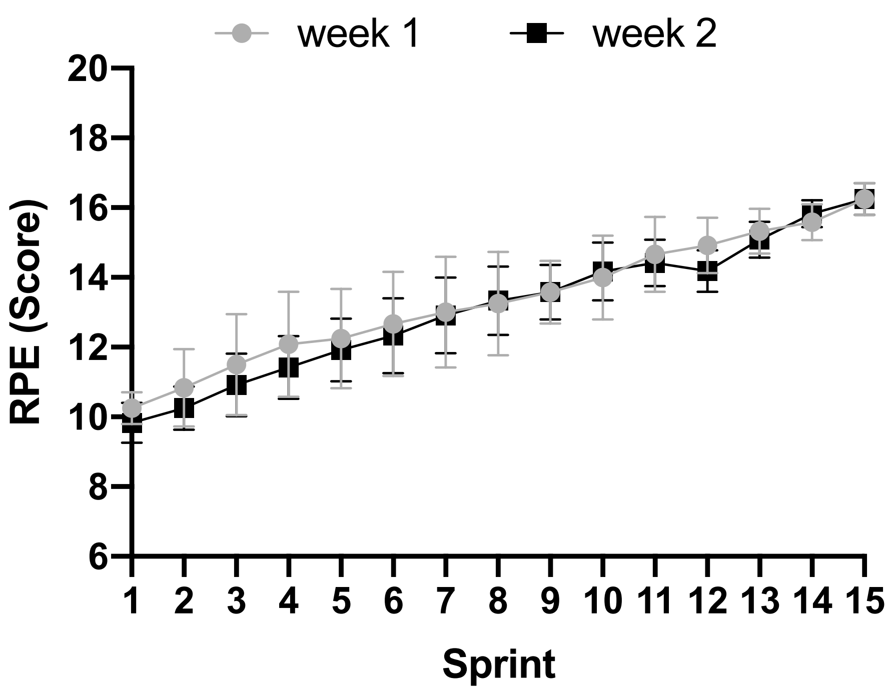

Figure 1. Rate of perceived exertion (RPE) values for each sprint, for the two sessions (week 1 and week 2), data is shown as means ± SD.

The reproducibility of the recovery markers at baseline and 24 hours post exercise in shown in Table 1. Most parameters showed a greater variability at 24 hours post-exercise compared to when assessed pre-exercise as reflected by a higher CV and ICC.

Table 1. Reproducibility and smallest worthwhile changes (SWCs) for recovery markers assessed prior to (pre-exercise) and 24 hours post two identical bouts of repeated sprint exercise one week apart (n = 13).

	Pre-exercise				24 hours post-exercise			
	Difference (wk 2 – wk 1)	CV (%)	ICC	SWC (%)	Difference (wk 2 – wk 1)	CV (%)	ICC	SWC (%)
CK (U/L)	-2.0±77.7	25.6	0.58	9.81	-190.8±163.1	44.5	0.57	11.54
CMJ Height (Best of *n*)								
CMJ cm (1)	0.0±2.4	4.0	0.92	3.61	0.4±4.1	7.7	0.60	2.91
CMJ cm (2)	-0.6±3.2	4.7	0.89	3.33	0.6±4.2	7.6	0.59	3.06
CMJ cm (3)	-0.2±3.9	6.6	0.82	3.34	-0.2±4.0	6.9	0.67	3.17
CMJ Height (Average of *n*)								
CMJ cm (1)	0.0±2.4	4.0	0.92	3.61	0.4±4.1	7.7	0.60	2.91
CMJ cm (2)	-0.5±2.8	4.2	0.91	3.49	0.1±4.1	7.9	0.59	3.11
CMJ cm (3)	-0.3±2.9	5.1	0.90	3.48	-0.6±4.2	8.4	0.61	3.17
VAS (mm)	-0.7±2.3	49.2	0.69	20.71	0.3±3.1	44.8	0.42	17.98
WB (score)	-0.3±2.0	5.9	0.63	2.11	0.3±2.3	7.1	0.52	2.19

Difference, mean difference (week 2 – week 1) ± SD; CV, coefficient of variation; ICC, intra-class correlation coefficient; SWC, smallest worthwhile change expressed as a percentage; CK, creatine kinase; CMJ, countermovement jump; VAS, visual analogue scale; WB, well-being questionnaire.

To assess whether the response to exercise differed significantly between the two identical bouts, change scores (24 hours post - pre-exercise) were compared between week 1 and week 2. Individual changes and mean group changes in response to the exercise bout in both weeks are shown in Figure 2. In week 1, there was a significant increase in CK in response to repeated sprint exercise (mean 199.6 ± 195.46 uL), but in week 2 this was attenuated (10.8 ± 14.95 uL), with a significant difference between the change scores between the two weeks ($p < 0.01$). CMJ height was significantly reduced by approximately 7% 24 hours post exercise on both weeks ($p < 0.05$), but there was no difference in responses between week 1 and week 2 ($p = 0.784$). There was no significant effect of repeated sprint exercise upon muscle soreness or WB 24 hours later in either week, and no difference in the change scores between the two weeks ($p = 0.70$ and $p = 0.31$ respectively).

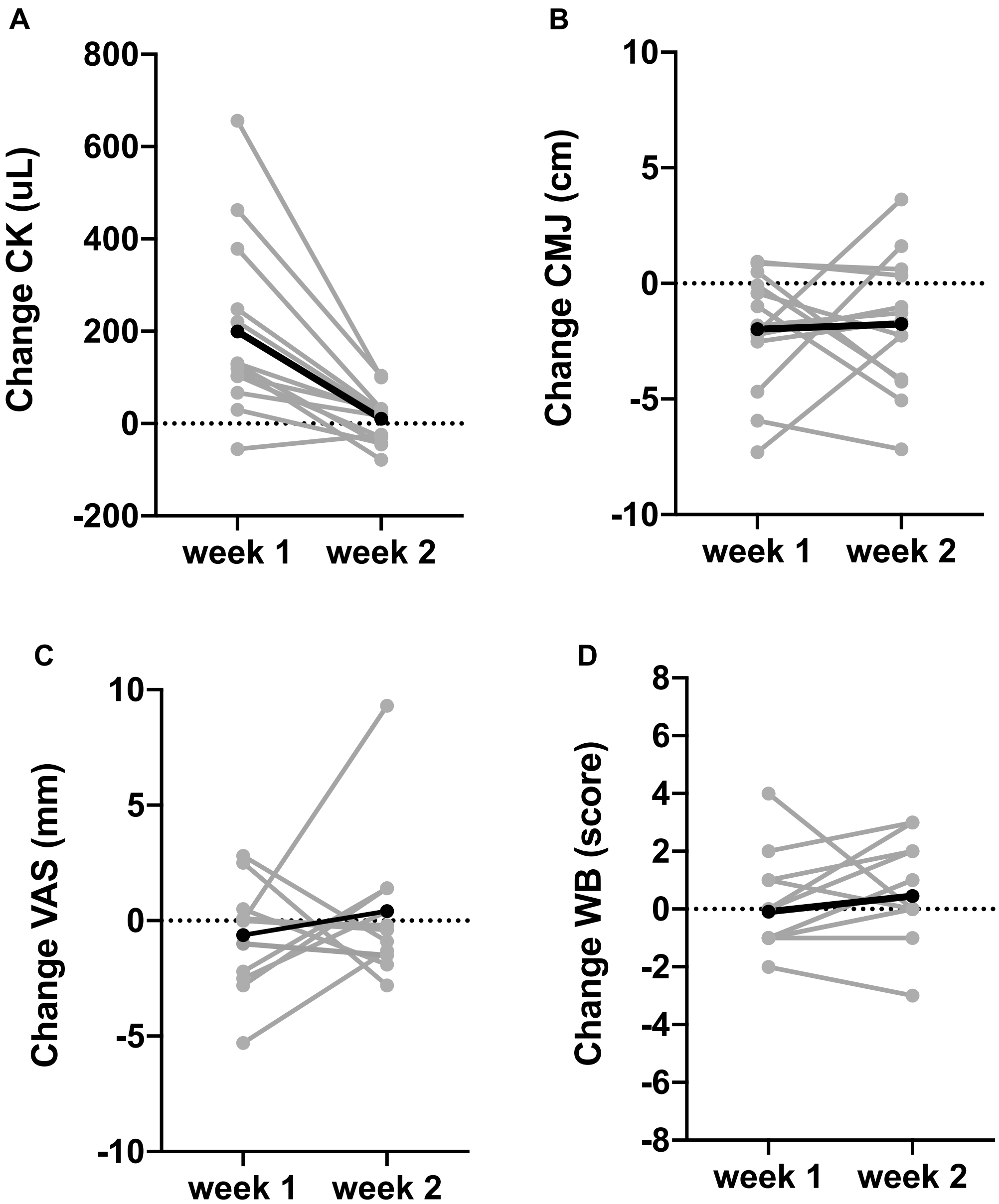

Figure 2. Changes (post-pre exercise) in response to the exercise bout in week 1 and week 2 for (A) creatine kinase (CK), (B) countermovement jump height (best of 3), (C) visual analogue scale (VAS) for muscle soreness, and (D) Wellbeing questionnaire (WB). Grey lines represent individual, and dark line represents group mean.

DISCUSSION

The present findings show that CMJ and the WB questionnaire appear to be the most reproducible objective and subjective markers of those studied in this population of college-aged males. Interestingly height derived from a single CMJ appeared to be just as reliable as that derived from multiple jumps. Most markers also showed greater variability when measured 24-

hours post an identical bout of repeated sprint exercise compared to pre-exercise. The CK response was significantly attenuated following the second exercise bout, indicating a repeated bout effect, but this effect was not evident for CMJ, WB or muscle soreness. Moreover, for all parameters measured, CVs were greater than the SWC, highlighting the importance of considering both the CV and SWC when interpreting the relevance of changes in these parameters.

Our finding of a CV of ~26% (ICC 0.58) for CK pre-exercise, indicates a high intra-individual variability. Although limited previous studies have reported the intra-individual CV, this corresponds to the previous work by Roe et al. (24) using the same methodology, finding a CV of 26% in in elite male youth rugby union players, tested five days apart during a non-training week. Others have similarly reported a between day CV of 27% in male rugby league players (29). Less studies have reported the reproducibility of the CK response to exercise. We observed a CV of 45% when assessed 24 hours after repeated sprint exercise, demonstrating a much greater variability in the CK response to an identical exercise bout. These data support limited previous findings in trail runners, whereby a CV of ~20% for CK was observed at rest and this increased to ~34% when assessed 24 hours after identical 15.6km trail runs in experienced runners (11).

A clear explanation for such variability post-exercise in the present study appears to be due to a repeated bout effect, whereby the CK response was much greater after the first compared to second bout. Others have demonstrated a repeated bout effect for CK using laboratory fatigue protocols such as isokinetic dynamometry (4), but findings are less consistent on whether this also occurs in response to more team sport specific exercise such as repeated sprints. Changes in velocity and direction during a bout of repeated sprints appear to elicit muscle damage (17, 18). In response to two identical Loughborough Intermittent Shuttle Tests in 8 Premier League male footballers, CK increased substantially in response to exercise but there were no differences in CK concentrations following the two identical bouts (21). In contrast, Brown et al. (3) observed in female dancers completing either two identical bouts of a sport-specific dance protocol or repeated sprint protocol, that the CK response was consistently lower 24, 48 and 72 hours following the second bout, regardless of the exercise protocol. Differences in the training status, sample size or exercise protocols could be potential explanations for differences in findings. Our findings support these previous findings in females (3) indicating that in college age male team sport athletes, CK responses to an identical bout of repeated sprint exercise are not reproducible at either a group or an individual level. These findings have implications for both researchers and practitioners using CK as a marker of exercise recovery in this population. There are several other well established limitations of CK as an indirect marker of muscle damage, including wide individual variability as a result of non-modifiable factors such as ethnicity, age and sex, as well as wide variability in responses to exercise (see Baird et al. (1) for a review). However as noted by others CK is still considered a valuable biomarker of muscle damage (20) and may still have some relevance given the magnitude of change that can occur (24) (in the present study, a 144% increase was observed after the first bout of exercise).

In contrast to CK, CMJ height showed much greater reproducibility both pre- and 24 hours post exercise and showed the greatest reproducibility of all markers studied. Pre-exercise CVs ranged from 4-6% depending on whether the best of or average of one or three CMJ's was used, and ICCs ranged from 0.82-0.92, indicating a low variability and high repeatability. This corresponds to previous reports in a range of different sports and populations including Australian Rules football (7), rugby union (24), male college level team sport athletes (12), and middle aged men (8). Interestingly, pre-exercise jump height derived from the first CMJ had a slightly lower CV compared to when the average or best of 3 jumps was used. Roe et al. (24) showed similar variability in jump height regardless of whether the best of 1, 2 or 3 jumps were used (CVs of 5.2, 4.9 and 4.6% respectively). In contrast, others (28) have shown that when taking the mean of jumps, increasing the number of trials improves the reliability. However, the vast majority of studies and practitioners use the best value (5). The present findings support recommendations from a recent meta-analysis for the use of average values for CMJ height (5). Moreover, our results in college level male athletes suggest that following a familiarization jump as was conducted in the present study, single CMJ height is just as reproducible as taking the best or average of 3 jumps, as well as being a more time-efficient approach for practitioners.

While the variability was slightly greater when assessed 24 hours post-exercise (CVs of 7.9 to 6.6% and ICCs 0.60 to 0.67 for one to three jumps respectively), it is still within the previously accepted criteria of a CV <10% being considered an indicator of a reliable measure (5, 7, 12, 28). Moreover, the approximate 7% reduction in CMJ height 24 hours post-exercise was similar in response to the two identical bouts of exercise, indicating no evidence of a repeated bout effect. Interestingly, Brown et al. (3) observed a similar effect in females, where although a repeated bout effect was observed for CK, the reduction in CMJ 24 hours post exercise was identical in response to both bouts of exercise. Others have similarly shown reproducible reductions in CMJ jump height 24 hours following identical 15.6km trail runs (11) and in CMJ peak power output 24 hours following soccer matches (25). Overall, CMJ height is a reliable measure assessed pre and post exercise, and therefore a useful marker of recovery in studies using repeated measures designs.

Assessing subjective measures is also essential for monitoring recovery. However, our findings show poor reliability of single ratings of muscle soreness both pre- and post-exercise with CVs of >40%. Easthope reported the reproducibility of muscle soreness prior to and post trail running to be 17% and 47% respectively (11). One explanation for high CVs for VAS scores is the comparison of single time-points against each other. Using visual analogue scales to assess appetite ratings, we have previously found CV's ranging from 35 to 68% for single fasting ratings, whereas when averages of multiple ratings were used, the variability was much less (CVs of 11-20%) (16). Although an approach often taken to assess muscle soreness, the use of a single rating likely contributes to the large variability observed, and it is likely that the use of a mean of several ratings might reduce the variability. This is an area that warrants further study.

In contrast to subjective muscle soreness, WB, determined by participants scores summing five different items, demonstrated a much greater reliability, highlighting its value in player monitoring. Self-reported ratings of wellbeing have been considered an efficient method of monitoring overtraining and recovery (13). Pre (CV 5.9%) and post exercise (CV 7.1%) reliability statistics indicate that the WB questionnaire used is reliable, however, WB score did not change 24 hours after the repeated sprint exercise bout in either week. In contrast, in professional rugby players, WB was significantly reduced 24-hours post-match and was found to return to baseline after four days (22). The lack of change in the present study may be due to the difference in exercise protocol, and population studied. Overall, our findings showing good reliability suggests that regular use of the WB questionnaire may be a useful and cost-effective test to monitor WB, in conjunction with objective markers of recovery.

Some methodological aspects of the current study should be considered. We assessed whole blood CK, using a method that is commonly used in the applied setting. We assessed responses to exercise at 24 hours post exercise, as this time-point has been shown to elicit the highest CK post-exercise (9). Furthermore, we assessed CMJ height as commonly used and recommended for various reasons including its simplicity (5). However, it is acknowledged that findings could be different for other outcomes.

Overall, the results of the present study provide insight into the reproducibility of both objective and subjective markers of recovery assessed before and after exercise in college-aged males. This knowledge is important for practitioners, athletes, and researchers, to determine whether any changes observed in these markers are meaningful. CMJ height appears to be the most reproducible of all markers, with one jump demonstrating high reliability, while the WB questionnaire was the most reproducible subjective marker. These measures may be particularly useful for researchers and practitioners to monitor recovery of college-aged male athletes. Practical implications of the findings are described below:

- Individual changes in CK and muscle soreness should be interpreted with caution due to the large intra-individual variability observed.
- Evidence of a repeated bout effect for CK following repeated sprint exercise, indicates that independent design studies may be preferable using this outcome measure in this population.
- Height derived from a single CMJ showed high test-retest reliability (CV: 4%) and represents a time-efficient objective marker of recovery.
- CMJ height and the WB questionnaire represent reliable, simple and cost-effective objective and subjective markers of recovery.
- Evidence of CVs being greater than the SWC for all parameters, highlights the importance of considering both the CV and SWC when interpreting changes.

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