Does exercise intensity affect wellness scores in a dose-like fashion?

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ABSTRACT

Wellness questionnaires are common in monitoring systems, yet the sensitivity to variations in acute training intensity is unclear. This study examined the controlled dosage effects of differing exercise intensities on wellness variables and subsequent associations with neuromuscular performance. Participants (n=10) completed low-, moderate- and high-intensity conditions of a 90min simulated football match shuttle running protocol scaled relative to beep test scores. The protocols were completed in a randomised and counterbalanced fashion matched for time of day. Wellness (sleep quality, readiness to train, soreness, fatigue, stress, mood, motivation) and neuromuscular performance (maximal voluntary contraction, countermovement jump, 6s cycle-ergometer sprint) were assessed pre-, post- and 24h post-exercise. Heart rate (HR) and rating of perceived exertion (RPE) were recorded during, and session RPE (sRPE) after exercise. Generalised linear mixed models demonstrated main effects between conditions with increased HR, RPE and sRPE (*P* <0.03; *d* >0.8) responses from the low-high condition. Total and z-score wellness showed no significant differences between trials at any time-point (*P* >0.05; *d* =0.03-0.91). Fatigue was lower 24h post-exercise for the low, compared to moderate and high conditions (*P* =0.006-0.047; *d* =1.20-1.77). Ratings of fatigue and soreness increased from pre- to 24h post-trial (*P* <0.003; *d* =0.96-2.48), while total wellness and readiness to train decreased over time (*P* <0.04; *d* =0.91-1.86). Wellness showed limited capacity to differentiate training intensities. Practitioners should be aware while wellness may be highly practical, it may be limited to solely determine athlete accommodation of load considering the strength of association observed with the applied load.

INTRODUCTION

Athlete monitoring practices are considered an integral component of high-performance sports settings, principally seeking to enhance physiological adaptations (i.e., maximise performance capacity), while limiting undue negative costs of training (e.g., illness, injury, or excessive fatigue) (13, 27). The use of subjective measures (e.g., questionnaires) in monitoring systems is of increasing interest, as the consideration of non-training stressors and holistic viewpoints of monitoring athletes become more prevalent (7, 15, 27). These measures typically assess perceived physical, psychological and/or social well-being (27), and are supported due to their inexpensiveness, and reported superiority in monitoring training compared to conventional objective (e.g., physiological, biochemical, immunological) markers (7, 27). Recently, the use and importance of wellness questionnaires are increasing as existing validated psychometric measures (21, 26) are perceived as non-specific, time-consuming and impractical for use (11, 27, 29). These measures are highly prevalent in applied sport environments, with 80% of questionnaires in these settings reportedly being wellness questionnaires (29), with the measures typically completed daily, consisting of 4-12 items measured on Likert scales (1-5/1-10) and framed as „how are you feeling currently‟. Despite this interest, the aforementioned superiority of subjective over conventional objective monitoring markers relates primarily to established psychological questionnaires (21, 26).

In practice, wellness measures are purportedly used to evaluate how an athlete is tolerating the training load, and their subsequent readiness to train/compete. Current evidence linking wellness and training load largely consists of retrospective in-season studies descriptively portraying changes from match-day to match-day. These data suggest progressive improvements in wellness are experienced as competition approaches (11, 12, 18). However, it is questionable if these results are confounded by competitive traits, such as a motivational bias in perceiving oneself as recovered for the next week"s game. This notion may be supported by the absent effect of training load on wellness when controlling for days-to-match (9). Further, associations between changes in wellness and mechanical workload (e.g., maximal velocity, high speed running) demonstrate divergent trends, with trivial to moderate effects observed (9, 10, 17, 31). While the interaction between wellness and load in a competitive environment is important, there are variables (e.g., motivation, monitoring, win/loss, home/away games) that may affect this relationship. Preliminary evidence suggests subjective wellness may be useful in monitoring training responses (11, 18, 31); however, the supporting evidence is highly variable (9, 10, 12), and further investigation is required.

The understanding of altered wellness responses and objective fatigue markers (e.g., central and peripheral fatigue, motivation, performance), time-course expression, or if wellness can differentiate acute changes in exercise intensity remains unclear. With the popularity of wellness measurement scales, it is important to understand these relationships in isolation of competition demands, and notably, to tie them to practically meaningful changes in neuromuscular performance outcomes (30). Further, it is imperative to determine the capacity wellness measures have in differentiating between exercise intensities if wellness responses are to be utilised in modifying or assessing training load responses. Accordingly, this study aims to examine the dose-response relationship of three different exercise intensities on wellness responses, and the time-course expression of perceptual variables and neuromuscular performance measures.

METHODS

Experimental Approach to the Problem

A randomised and counterbalanced cross-over design was implemented to examine the effects of intermittent shuttle running exercise intensity on subjective wellness responses. The time-course expression of perceptual (i.e., wellness, rating of perceived exertion), and neuromuscular performance (i.e., countermovement jump, 6 s cycle-ergometer sprint and maximal voluntary contraction (MVC)) measures were collected pre-, post- and 24 h post-exercise. Participants completed four laboratory visits over four weeks, consisting of a familiarisation session and three experimental trials. Experimental trials were separated by a period of 5-7 days. Participants maintained their regular exercise and dietary behaviours, and abstained from alcohol and caffeine for 24 h before each testing session. Participants maintained their typical exercise schedule, however, they abstained from exercise for 24 h before each testing session. All data collection procedures were matched for time of day in standardised laboratory conditions. A 24 h food, fluid and physical activity recall was completed on the first testing day, and participants replicated food and fluid intake for the subsequent laboratory visits.

Subjects

Ten male amateur team sport athletes (24.9 ± 3.8 y, 181.2 ± 5 cm, 77 ± 7.3 kg, VO_{2max} 50.2 ± 3.3 $ml\cdot kg^{-1}$) completed this study. The participants were trained individuals (4 ± 1 sessions $week^{-1}$, 235 ± 51 min $week^{-1}$) completing a combination of team-sport training inclusive of technical and conditioning aspects, and were free of illness and injury. All participants provided written informed consent, and ethical approval for study procedures was provided by the University Human Research Ethics Committee.

Procedures

Exercise Protocol

Before commencing experimental trials, participants completed a progressive shuttle run VO_{2max} test, with these data used to determine the requisite running speeds for the experimental shuttle protocol (24). Exercise during the experimental sessions involved the completion of three trials of a modified Loughborough Intermittent Shuttle Test (LIST). Activity patterns of the LIST are representative of football match-play (23), with similar physiological, biochemical and neuromuscular responses being demonstrated (16, 23). The LIST protocol consists of 90 min of intermittent exercise involving the following periods and intensities: 3 x 20 m at a walking pace; 1 x 20 m at maximal sprint; 4 s recovery period; 3 x 20 m at a pace corresponding to 35%, 45% or 55% of VO_{2max}; 3 x 20 m at a pace corresponding to 75%, 85% or 95% of VO_{2max}.

Each cycle of the above exercise took 15 min to complete. This football simulation was completed six times in succession, with 3 min of recovery between exercise bouts. The fluctuating shuttle running segments were regulated via an individualized tape recording based on their running speed. For the purposes of the research question, the primary differentiation between the trials was via manipulating the pace as a percentage of the participant‟s prior completed VO_{2max} test. This resulted in a low-intensity trial (35% and 75% of VO_{2max}), a moderate-intensity trial (45% and 85% VO_{2max}) and the completion of the original LIST format as the high-intensity trial (55% and 95% of VO_{2max}). This exercise was completed on an outdoor (29.1 ± 3.2 °C, 59.2 ± 10.7% relative humidity) tartan running track where participants were supplied 600 mL of water to consume *ad libitum*.

Physiological measures

Upon arrival at each laboratory visit, participants provided a mid-stream urine sample to ensure presentation in a euhydrated state as per urine specific gravity (< 1.020) (28). A heart rate (HR) transmitter belt (T34, Polar Electro-Oy, Kempele, Finland) was then fitted, with HR recorded at each 5 min interval during the LIST trials.

Performance measures

Countermovement jump (CMJ) height and cycle ergometer sprint performance were assessed using an Optojump (Microgate, Bolzano, Italy) and Wattbike (Wattbike Pro, Nottingham, UK), respectively, pre-, post-, and 24 h post-exercise. Participants completed three continuous maximal CMJ efforts commencing from a standing position, with their hands positioned on their hips to eliminate arm swing, self-selected countermovement depth and instructions to jump as high as possible. Mean CMJ height is sensitive to neuromuscular fatigue (3) and has high levels of reliability (CV= 5.1%) (6). Cycle ergometer sprint performance was conducted as per Wehbe et al. (33). Briefly, this involved participants completing a 5 min self-paced steady state warm-up, inclusive of a maximal 6 s effort at the end of each minute. Immediately before beginning the maximal 6 s sprint commencing from a static position, the air and magnetic brakes were set at levels 10 and 4 respectively (33) and the test began at the researchers command. Subsequently, two 6 s maximal sprints were completed with verbal encouragement, and trials were separated by a 1 min active recovery. The highest power output (peak power) and cadence of the two trials were recorded (CV= 2.4%, ICC= 0.97) (33).

Neuromuscular function

MVC torque was measured on an isokinetic dynamometer (Biodex Medical Systems, Shirley, New York, USA) connected to a host computer and customised software (16-bit PowerLab 26T AD unit; AD Instruments, Sydney, Australia). Participants completed a 5 x 5 s MVC protocol with a 30 s rest between repetitions. Standardisation of the dynamometer setup and isolation of the right knee extensors were achieved as previously described (20).

Supra-maximal electrical stimulation of the right femoral nerve was administered using reusable self-adhesive gel electrodes (diameter 3.2cm; Pals; Axelgaard Manufacturing Co. Ltd., Fallbrook, CA) located 3 cm distal to the inguinal ligament bordering the femoral triangle. An additional reusable gel adhesive electrode (5 x 9 cm) was positioned on the medio-posterior aspect of the right upper thigh, on the border of the gluteal fold. A single square-wave pulse with a 50 µs width (400 V with a current of 100-900 mA) was delivered by a Digitimer DS7AH stimulator (Digitimer Ltd., Welwyn Garden City, Hertfordshire, England). A twitch ramp procedure with incremental increases in stimulus intensity was administered until a plateau occurred to determine appropriate intensity of stimulation before the maximal voluntary contraction (MVC). The final current was then increased by 10 % to ensure supramaximal stimulation. A superimposed twitch was delivered during each MVC approximately 1 – 2 s following commencement of the repetition to coincide with an observed plateau in voluntary torque. A further stimulus was administered to the resting muscle immediately upon cessation of the MVC to determine voluntary activation. Voluntary activation (VA) was calculated using the twitch interpolation technique (2) and was subsequently averaged across the 5 MVC repetitions. Peak voluntary torque was determined as the mean torque of the preceding 25 ms following the delivery of the stimulation. The superimposed torque was recorded as the peak torque value recorded 100 ms following stimulation. The interpolated twitch torque was calculated as the difference between the peak voluntary torque and the superimposed torque. This technique has previously displayed high levels of reliability (CV= 1.40% and 3.78%; ICC= 0.85 and 0.99) for VA and MVC respectively (2).

Subjective measures

Wellness measures were recorded upon waking, pre-, post-, and 24 h post-exercise. Participants were familiar with wellness measures, however their use and implementation were reiterated by the researcher during the familiarisation trial. The 7-item wellness questionnaire identified perceived ratings of sleep quality, readiness to train, general muscular soreness, fatigue, stress, mood, and motivation. The questions were referenced as "How do you feel at this moment", and a 5-point Likert scale (5 representing optimal and 1 representing poor) was used, with the scale initially anchored on a mid-point. Total wellness represented an overall score found by summing the scores from each wellness item, and a z-score ((participant score-participants average)/standard deviation) was calculated for each wellness sub-scale. The wellness questionnaire was designed to be similar to those previously reported (9, 10, 18) and are anecdotally known to reflect those used in professional sport. Wellness questionnaires have previously reported CV of 7.1% in team sport athletes (25). Participants completed the questionnaire in a quiet side room to avoid peer influence on a purpose-built mobile application (Catapult Technologies, Melbourne, Australia).

Ratings of perceived exertion using the category-ratio 10-point scale (CR-10) were collected immediately following each 15 min exercise block throughout the LIST and recorded manually by the researcher. An overall session rating of perceived exertion (sRPE) was obtained 10 minutes following the exercise trial (8) via a purpose-built mobile application (Catapult Technologies, Melbourne, Australia).

STATISTICAL ANALYSIS

Data are reported as a mean ± standard deviation unless otherwise specified. Descriptive methods of data normality were completed (i.e., distribution plots, skewness, kurtosis, and outliers) before analysis of the interaction between monitoring measures and exercise bouts were completed using generalised linear mixed models (GLMM). When the assumption of normality was not met, the target distribution and relationship link in the GLMM were adjusted to Gamma Regression, and the model was repeated. The independent variables included in the model were condition and time-point (with an interaction), and the participant specified as a random effect. Dependent variables included the performance, neuromuscular, physiological and subjective measures, respectively. The model was adjusted for multiple comparisons using the least significant difference (LSD). Spearman (*rho*) correlations examined the strength of the relationship between variables, and at separate time-points and are interpreted as follows: 0.00-0.30 as negligible, 0.30-0.50 is small, 0.50-0.70 is moderate, 0.70-0.90 is strong, and 0.90 to 1.00 is very strong. The analysis was performed using Statistical Package for Social Sciences (IBM SPSS v.22, Chicago, USA). Statistical significance was accepted when $P < 0.05$ and 95% confidence intervals (CI) have been included. Standardised effect sizes (Cohen‟s d) were calculated by dividing the mean difference by the average of their standard deviations. Effect sizes were then evaluated based on the smallest worthwhile difference, whereby an effect size of ≤ 0.2 is trivial, 0.2–0.49 is small, 0.5–0.79 is medium, and ≥ 0.8 is large (4).

RESULTS

Subjective Ratings

Table 1 shows significant main effects and large effect sizes between conditions for HR (P= 0.0001-0.003; d= 2.77-4.53; CI= 4.45-25.30), RPE (P= 0.001-0.03; d= 0.98-3.75; CI= 0.10-4.28) and raw sRPE (P= 0.001-0.004; d= 1.34-4.17; CI= 0.42-4.37). Differences between conditions for wellness sub-scales are demonstrated in Figure 1. Total and z-score wellness showed no differences between conditions at any time-point (P= 0.19 – 0.73; d= 0.03-0.91; CI= ˉ3.88-3.88). Ratings of readiness to train (P=0.03; d=2.0; CI= 0.04-0.82) and fatigue (P=0.007; d=4.8; CI= 0.11-0.68) demonstrated significant reductions and large effects for the moderate, compared to low conditions. Readiness to train and general soreness displayed significant decreases and large effects at 24 h post-exercise for the moderate compared to low intensity conditions (*P*= 0.04; *d*= 1.10-1.26; *CI*= 0.006-1.19). Perceptions of fatigue were also lower at 24 h post-exercise for the low, compared to the moderate and high conditions (*P*= 0.006-0.047; *d*= 1.20-1.77; *CI* = 0.006-1.194). Though no differences were distinguishing between the moderate and high condition (*P*= 0.42; *d*= 0.51; *CI* = $^{-}$0.69-0.29).

TABLE 1 HERE

Differences between time-points (pre-, post- and 24 h post-exercise) within each condition (low, moderate and high) for subjective measures are displayed in Table 2. Main effects for time within conditions demonstrated significant differences and large effect sizes for worse ratings of readiness to train (*P*= 0.002-0.04; *d*= 1.63-3.87; *CI*= 0.08-1.02), fatigue (*P*= 0.001; *d*= 2.56-5.53; *CI*= 0.24-1.13) and total wellness (*P*= 0.001; *d*= 4.40-6.83; *CI*= 0.98-4.39) scores at post- and 24 h post- compared to pre-exercise.

FIGURE 1 HERE

TABLE 2 HERE

Neuromuscular

Figure 2 shows differences between time-points (pre-, post- and 24 h post-exercise) within each condition (low, moderate and high) for performance measures. VA showed significant decreases at 24 h after the high-intensity condition when compared to the low-intensity condition (*P*= 0.01; *d*= 1.37; *CI*= 2.61-17.88). VA also demonstrated significant reductions at pre- to post-exercise, and further again 24 h post-exercise within the low-intensity condition (*P*= 0.007-0.02; *d*= 1.57-1.93; *CI*= 1.19-22.23). There were no other significant differences between conditions for other neuromuscular measures (*P*= 0.09-0.24). Main effects for time within conditions was shown for cycle-ergometer peak power (PP) (*P*= 0.001; *d*= 1.90-3.87; *CI*= 45.5-126.5), CMJ height (*P*= 0.001-0.02; *d*= 2.88-3.46; *CI*= 0.66-2.14), and VA (*P*= 0.004-0.01; *d*= 1.10-1.48; *CI*= 0.90-10.9) scores at post- and 24 h post-compared to pre-exercise. Cycle-ergometer PP was higher pre- than post-exercise, within each condition (*P*= 0.001; *d*= 0.49-0.69; *CI*= 34.88-155.9) and at 24 h post- compared to post-exercise (*P*= 0.001-0.02; *d*= 0.34-0.74; *CI*= 8.93-155.5).

FIGURE 2 HERE

Correlations

Moderate correlations between MVC and cycle-ergometer PP, CMJ height, fatigue, stress, total and z-score wellness were seen at pre-exercise (*P*= 0.02-0.04; *r*= 0.48-0.58). Cycle-ergometer PP and CMJ height were low to moderately correlated at pre-trial with ratings of fatigue, stress, and total wellness (*P*= 0.02-0.03; *r*= 0.38-0.69). There was a moderately strong correlation for MVC to cycle-ergometer PP, CMJ height and flight time post- and 24 h post-exercise which was significant (*P*= 0.001-0.02; *r*= 0.54-0.66). Cycle-ergometer PP was also low to moderately correlated with CMJ height, flight-time, readiness to train, stress and mood post-exercise (*P*= 0.02-0.04; *r*= 0.36-0.67), while CMJ height was moderately correlated with stress and mood (*P*= 0.002-0.01; *r*= 0.44-0.53). Finally, cycle-ergometer PP showed strong correlations with CMJ height and flight time (*P*= 0.001; *r*= 0.80-0.81), and negligible correlations to stress (*P*= 0.01; *r*= 0.17) 24 h post-exercise.

DISCUSSION

To the author‟s knowledge, this study is the first to investigate the efficacy of wellness questionnaires in differentiating between acute changes in exercise intensity and their acute time-course expression independent of competitive demands. These data demonstrated wellness measures to have limited capacity in distinguishing simulated football match shuttle running intensities compared to conventional sRPE and HR training load indices. Importantly, however, wellness markers of general soreness, fatigue and readiness to train may be useful in determining the time-course expression of perceived capacity to perform following team sports exercise. Statistically significant correlations between directional changes in performance (e.g., cycle-ergometer PP and CMJ Height) and neuromuscular measures (e.g., MVC) and wellness items of stress, mood, fatigue and total scores were also observed. These results indicate wellness questionnaires may be useful in understanding an athlete's perceived capacity to perform following an exercise bout. Nevertheless, caution should be applied as such measures may not be able to differentiate between different exercise intensities. This has implications for the purposed sole use of wellness questionnaires in evaluating training status, as previous mechanical loads may not be accurately reflected in questionnaire responses.

The implementation of simple, customised wellness questionnaires in high-performance environments are common. Previous literature has indicated wellness may be a useful measure, although taken in the context of descriptively analysing in-season data may not fully elucidate the utility of wellness in monitoring load. Progressive improvements in wellness responses have typically been reported from game-day to game-day for AFL (9, 11), NFL (12), rugby league (18), and football players (17, 31). However, it is questionable whether this represents sensitivity to real fluctuations in physical recovery, or if the changes are a proxy for motivation to be recovered (10). It has also been previously proposed there is a relationship between the perceived recovery and restoration of performance-related outcomes (5). For example, the influence of competitive demands may manifest in wellness responses that reflect the motivation to be perceived as fully recovered by game-day. These responses may also be an example of elite athletes" abilities to endure and override physiological fatigue through high levels of motivation (10). This may explain previous research modelling wellness-load relationships, indicating if the model controlled for days-to-game, training load showed no effect on wellness (10). Aligning with previous literature, the current data does suggest that wellness variables may be useful in identifying the time-course expression of perceived physiological readiness. Importantly, this study supports these results in isolation of competitive demands, and any influence motivation may have upon wellness variables.

The extent to which wellness measures can differentiate between training loads may be a critical element in their role within a monitoring system. This would ensure questionnaire data can be acted upon appropriately when modifying or prescribing training load. However, research investigating the impact wellness scores have on external load has shown a large variance in responses, with trivial to large relationships being identified across multiple sports (9, 12, 17, 31). Interestingly, a novel approach of normalising running performance variables to players" RPE and playing time demonstrated improved magnitude of correlations to wellness measures (14). These conflicting findings may be attributed to the context of the collection, analysis, and the impact competitive demands may have on wellness responses. Recent research may demonstrate this, with in addition to the aforementioned motivation factors, match location and outcome (i.e., win, lose or draw) affects wellness responses in the days following a match (1). This may suggest an influence of pacing strategies in team-sports, with data indicating (9) a subconscious reduction in „incidental" movement strategies when investigating wellness-player load relationships. The current study suggests wellness variables, independent of these factors, have a limited capacity to differentiate between fluctuations in exercise intensity. The sRPE and HR responses make this particularly evident, with results showing clear distinctions between low, moderate and high exercise intensity. These results may imply competitive demands highly contribute to wellness responses and may affect the responses to a greater extent than actual variations in load. However, given the results of this study taken in the context of previous research, practitioners should be aware that while wellness may be a highly practical measure, it may be limited in scope in determining if load should be modified.

The statistically significant, albeit small, correlations between wellness variables and performance markers identified in this study indicates subjective indices of perceived readiness to be associated with physical or physiological fatigue, resulting in decreased muscular performance. These results confirm previous reports linking the perception of recovery, and recovery strategies, to the physiological restoration of performance-related outcomes (5, 19). This study demonstrates the monitoring of the time-course expression of wellness responses may have some value, but practitioners should consider the small *r* values and the responses may be influenced by external factors (e.g., life stressors). This confirms anecdotal and data-driven approaches of the need to consider multiple markers of load to inform different aspects of decision-making processes relating to recovery and performance (13). Examining the current body of evidence may begin to suggest confounding factors (i.e., motivation, pacing, competitive demands, win/loss, home/away) in team-sports may play a role in the relationships between wellness and objective markers. This may explain some differences between this study (fixed-paced) and previous observational studies (effectively, self-paced) and may be a limitation of this work. There may also be differences between groups of team-sport athletes (e.g., AFL vs. NFL vs. Football) and this study utilised a broad cohort of athletes not from one specific sport, and may be acknowledged as an additional limitation of this study.

This study provides insight into the time-course expression of wellness independent of competitive demands, the relationships with measures of performance, and the sensitivity of wellness to acute fluctuations of training load. The results show select wellness measures (e.g., fatigue) may have a role in monitoring systems and assisting in determining an athletes‟ perceived ability to perform. The extent to which wellness markers relate to changes in exercise intensities remains unclear, and while there is some evidence relating wellness to changes in performance, more data is required to elucidate this relationship. Further research is also needed to understand underlying contributors to wellness responses, and the influence this may have on modifying training loads. This study may have been limited by its small sample size, and with a time-course expression not beyond 24 h. Additional time-points up to 72 h may have indicated differing results, although previous research has shown the sensitivity of wellness to load measures was reduced beyond 24 h (32), which was the primary outcomes measure of this study. Further, similar perceptual ratings have previously demonstrated no statistically significant differences at 72 h compared to 24 h post-exercise (22).

PRACTICAL APPLICATIONS

Perceived fatigue, readiness to train and overall wellness demonstrated changes in time-course expression in isolation of competitive demands, indicating specific sub-scales may be used to assess the time-course expression of perceived physical readiness. This finding may support the use of wellness to assess perceived recovery of team-sport athletes following matches. The correlations between total wellness, fatigue, stress and mood measures and performance outcomes further supported the use of wellness in this manner. Importantly however, wellness markers generally showed a limited capacity to differentiate between the fluctuating training intensities. This finding indicates caution should be applied when interpreting post-training and next-day wellness responses following training sessions, as the data may not accurately reflect the load applied. Therefore practitioners should be aware that making decisions on athlete recovery based solely on wellness may not be reliable, and that other monitoring measures should also be utilised.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to declare. The work received no external funding to declare.

REFERENCES

1. Abbott W, Brownlee TE, Harper LD, Naughton RJ, and Clifford T. The independent effects of match location, match result and the quality of opposition on subjective wellbeing in under 23 soccer players: a case study. *Res in Sports Med* 26(3): 262-275, 2018.
2. Allen G, Gandevia S, and McKenzie D. Reliability of measurements of muscle strength and voluntary activation using twitch interpolation. *Muscle & nerve* 18: 593-600, 1995.
3. Claudino JG, Cronin J, Mezêncio B, et al. The countermovement jump to monitor neuromuscular status: A meta-analysis. *J Sci Med Sport* 20: 397-402, 2017.
4. Cohen J. *Statistical power analysis for the behavioral sciences (rev.* Lawrence Erlbaum Associates, Inc, 1977.
5. Cook CJ and Beaven CM. Individual perception of recovery is related to subsequent sprint performance. *Br J Sports Med* 47: 705-709, 2013.

6. Cormack SJ, Newton RU, McGuigan MR, and Doyle TL. Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perf* 3: 131-144, 2008.

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

8. Foster C. Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exercise* 30: 1164-1168, 1998.

9. Gallo TF, Cormack SJ, Gabbett TJ, and Lorenzen CH. Pre-training perceived wellness impacts training output in Australian football players. *J Sports Sci* 34(15): 1445-1451, 2015.

10. Gallo TF, Cormack SJ, Gabbett TJ, and Lorenzen CH. Self-reported wellness profiles of professional Australian football players during the competition phase of the season. *J Strength & Cond Res* 31: 495-502, 2017.

11. Gastin PB, Meyer D, and Robinson D. Perceptions of wellness to monitor adaptive responses to training and competition in elite Australian football. *J Strength & Cond Res* 27: 2518-2526, 2013.

12. Govus AD, Coutts A, Duffield R, Murray A, and Fullagar H. Relationship between pretraining subjective wellness measures, player load, and rating-of-perceived-exertion training load in American College Football. *Int J Sports Physiol Perform* 13: 95-101, 2018.

13. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Medicine* 44: 139-147, 2014.

14. Ihsan M, Tan F, Sahrom S, et al. Pre-game perceived wellness highly associates with match running performances during an international field hockey tournament. *Eur J Sport Sci* 17: 593-602, 2017.

15. Kellmann M. Underrecovery and overtraining: Different concepts-similar impact. *Enhancing recovery: Preventing underperformance in athletes*: 3-24, 2002.

16. Magalhães J, Rebelo A, Oliveira E, et al. Impact of Loughborough Intermittent Shuttle Test versus soccer match on physiological, biochemical and neuromuscular parameters. *Eur J Appl Physiol* 108: 39-48, 2010.

17. Malone S, Owen A, Newton M, et al. Wellbeing perception and the impact on external training output among elite soccer players. *J Sci Med Sport* 21: 29-34, 2018.

18. McLean BD, Coutts AJ, Kelly V, McGuigan MR, and Cormack SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sports Physiol Perform* 5(3):367-383, 2010.

19. Minett GM and Duffield R. Is recovery driven by central or peripheral factors? A role for the brain in recovery following intermittent-sprint exercise. *Front Physiol* 5: 24, 2014.

20. Minett GM, Duffield R, Marino FE, and Portus M. Volume-dependent response of precooling for intermittent-sprint exercise in the heat. *Med Sci Sports Exerc* 43: 1760-1769, 2011.

21. Nässi A, Ferrauti A, Meyer T, Pfeiffer M, and Kellmann M. Psychological tools used for monitoring training responses of athletes. *Perf Enhanc & Health* 4(5): 125-133, 2017.

22. Nedelec M, Wisloff U, McCall A, Berthoin S, and Dupont G. Recovery after an intermittent test. *Int J Sports Med* 34: 554-558, 2013.

23. Nicholas CW, Nuttall FE, and Williams C. The Loughborough Intermittent Shuttle Test: a field test that simulates the activity pattern of soccer. *J Sports Sci* 18: 97-104, 2000.

24. Ramsbottom R, Brewer J, and Williams C. A progressive shuttle run test to estimate maximal oxygen uptake. *Br J Sports Med* 22: 141-144, 1988.

25. Roe G, Darrall-Jones J, Till K, et al. Between-days reliability and sensitivity of common fatigue measures in rugby players. *Int J Sports Physiol Perform* 11: 581-586, 2016.

26. Saw AE, Kellmann M, Main LC, and Gastin PB. Athlete self-report measures in research and practice: considerations for the discerning reader and fastidious practitioner. *Int J Sports Physiol Perform* 12: S2127-S2135, 2017.

27. Saw AE, Main LC, and Gastin PB. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *Br J Sports Med* 50(5):281–291, 2015.

28. Stand AP. Exercise and fluid replacement. *Med Sci Sports Exercise* 39: 377-390, 2009.

29. Taylor K, Chapman D, Cronin J, Newton M, and Gill N. Fatigue monitoring in high performance sport: a survey of current trends. *J Austr Strength Cond* 20(1): 12-23, 2012.

30. Thorpe RT, Atkinson G, Drust B, and Gregson W. Monitoring fatigue status in elite team-sport athletes: Implications for practice. *Int J Sports Physiol Perform* 12: S227-S2234, 2017.

31. Thorpe RT, Strudwick AJ, Buchheit M, et al. Monitoring Fatigue During the In-Season Competitive Phase in Elite Soccer Players. *Int J Sports Physiol Perform* 10(8): 958-964, 2015.

32. Thorpe RT, Strudwick AJ, Buchheit M, et al. The influence of changes in acute training load on daily sensitivity of morning-measured fatigue variables in elite soccer players. *Int J Sports Physiol Perform* 12: S2107-S2113, 2017.

33. Wehbe G, Gabbett T, Dwyer D, McLellan C, and Coad S. Monitoring neuromuscular fatigue in team-sport athletes using a cycle-ergometer test. *Int J Sports Physiol Perf* 10(3): 292-297, 2015.

Table 1. Mean, SD and 95% CI for session rating of perceived exertion (raw sRPE), heart rate (HR) and rating of perceived exertion (RPE) score of the LIST trials. * indicates significant differences and large effect size between each trial ($P < 0.05$; $d > 0.80$).

Table 2. Significant differences for wellness ratings (mean ± SD) between time-points (pre-, post- and 24 h post-exercise) within each condition (low, moderate and high). * Significant differences and large effect size for post- and 24 h post-exercise compared to pre- for total wellness (P= 0.009-0.04; d= 1.02-1.86; CI= 0.064-6.73). # Significant differences and large effect at post- compared to 24 h post-exercise for fatigue (P= 0.04; d= 1.38; CI= 0.20-1.19). * Significant differences and large effect size for post- and 24 h post-exercise compared to pre- for fatigue (P= 0.002-0.01; d= 1.32-2.48; CI= 0.10-1.74). + Significant difference and large effect size for pre- compared to post-exercise for readiness to train (P= 0.01-0.04; d= 1.52-1.75; CI= 0.22-1.58). # Significant differences and large effect size for 24 h post-exercise compared to pre- for general soreness (P= 0.04; d= 0.96; CI = 0.006-1.19). * Significant difference and large effect size for post- compared to pre-exercise for general soreness (P= 0.02 d= 1.33; CI= 0.10-1.29). + indicates significantly higher mood scores at pre- compared to post- and 24 h post exercise for mood (P= 0.01-0.03; d= 1.81-2.55; CI= 0.02-0.82)

Figure 1. Mean and individual values for Fatigue (A); Readiness to Train (B); General Soreness (C); and Total Wellness (D). A) * indicates significant differences and large effects at 24h between low and moderate condition, and between low and high condition. B) * indicates significant differences and large effects at 24h between low and moderate conditions. C) * indicates significant differences and large effects at 24h between low and moderate condition.

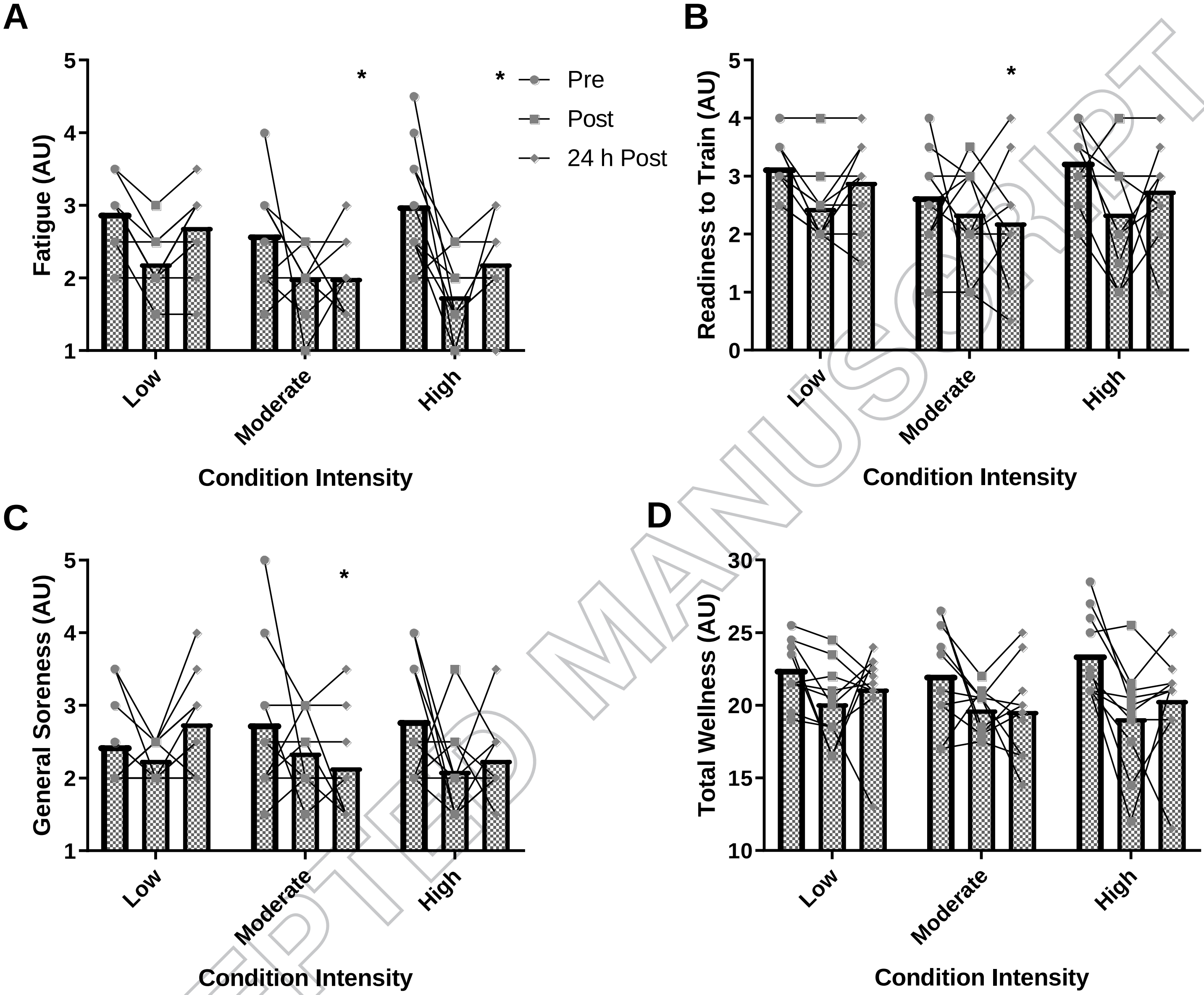
Figure 2. Mean and individual values for Cycle-Ergometer Peak Power (A), Countermovement Jump Height (B), Maximal Voluntary Contraction (C) and Voluntary Activation (D). A) ^ indicates significant differences and large effects at post- compared to pre- trial. C) # indicates large effects at post- and 24 h post compared to pre- across trials. + indicates large effects between low and high trials at post-, 24 h post, and at post- trial between moderate and high trials. D) ^ indicates significant differences and large effects at 24 h post- compared to post-trial. * indicates significant differences and large effect size at 24 h between low and high trials and at 24 h post compared to pre- after the high trial.

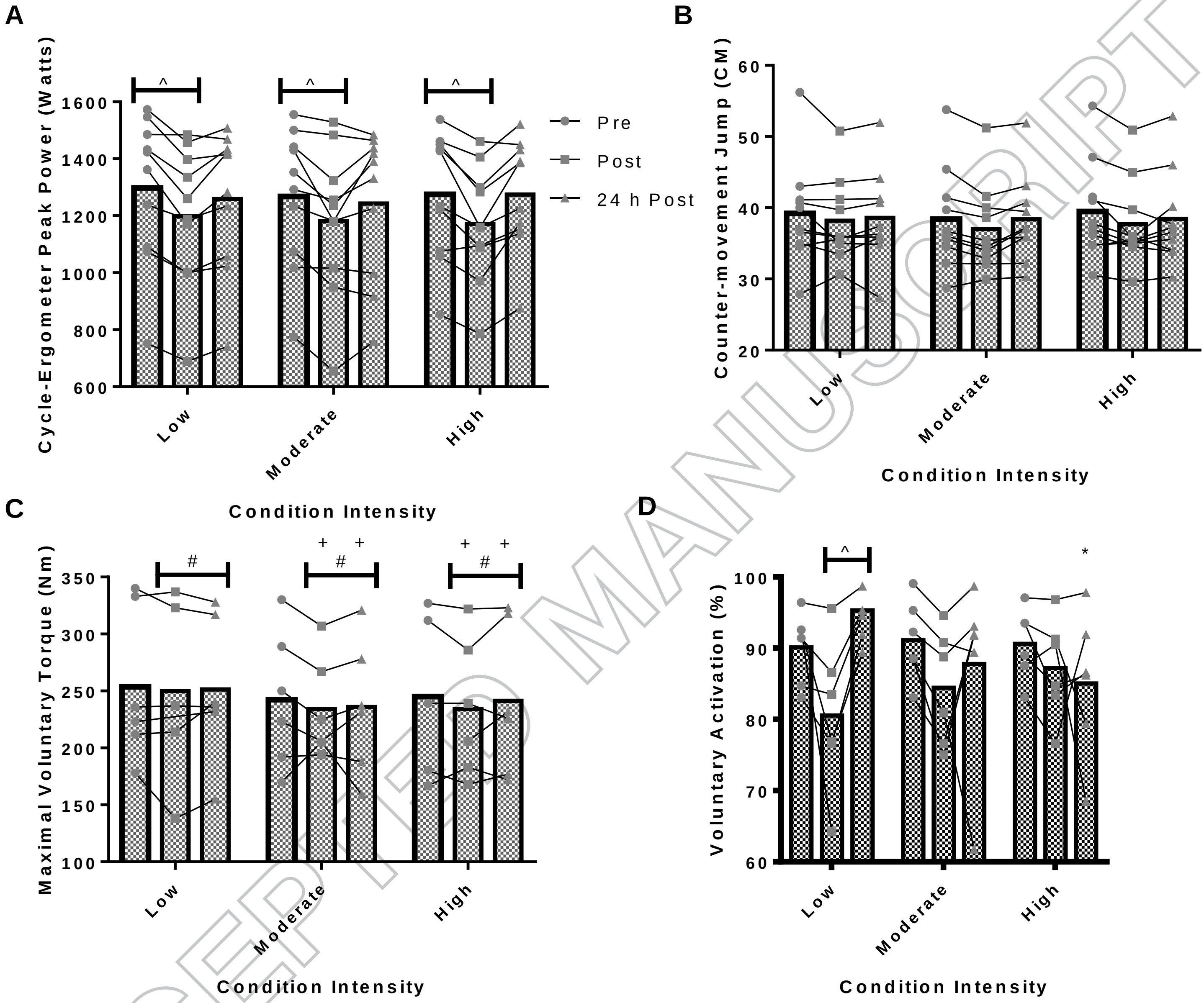
Table 1. Summary of sRPE (raw), HR and RPE values across each exercise trial.

Condition	sRPE (AU)	HR (bpm)	RPE (AU)
Low	4.3 ± 1.3* (CI=2.1-6.4)	145.1 ± 12.3* (CI=139.9-150.2)	3.4 ± 1.1* (CI=0.7-5.9)
Moderate	6.7 ± 1.3* (CI=2.1-6.4)	163.1 ± 4.2* (CI=157.9-168.2)	5.6 ± 1.6* (CI=3.0-8.2)
High	7.9 ± 1.2* (CI=5.7-10.0)	174.9 ± 4.7* (CI=169.6-180.0)	6.7 ± 1.4* (CI=4.1-9.2)

Table 2. Significant differences for wellness ratings (mean ± SD) between time-points (pre-, post- and 24 h post-exercise) within each condition (low, moderate and high).

Variable	Time-Point	Low-Condition	Moderate-Condition	High-Condition
Total Wellness	Pre-	22.5 ± 2.22	22.1 ± 3.62	23.5 ± 2.87
	Post-	20.15 ± 2.72	19.7 ± 1.55*	19.1 ± 3.76*
	24h-Post	21.1 ± 3.06	19.6 ± 3.27*	20.35 ± 3.54*
Fatigue	Pre-	2.9 ± 0.4	2.6 ± 0.7	3.0 ± 0.8
	Post-	2.2 ± 0.4$^{\#}$	2.0 ± 0.4*	1.7 ± 0.5*
	24h-Post	2.7 ± 0.5	2.0 ± 0.5*	2.2 ± 0.5*
Readiness to Train	Pre-	3.1 ± 0.4	2.6 ± 0.8	3.2 ± 0.6
	Post-	2.4 ± 0.6	2.3 ± 0.8	2.3 ± 1.0^{+}
	24h-Post	2.9 ± 0.7	2.2 ± 1.0	2.7 ± 0.8
General Soreness	Pre-	2.45 ± 0.64	2.75 ± 1.06	2.80 ± 0.85
	Post-	2.25 ± 0.26	2.35 ± 0.52	2.10 ± 0.61*
	24h-Post	2.75 ± 0.67	2.15 ± 0.66$^{\#}$	2.25 ± 0.54
Mood	Pre-	3.75 ± 0.35	3.85 ± 0.33	3.86 ± 0.31
	Post-	3.65 ± 0.57	3.55 ± 0.68^{+}	3.55 ± 0.68
	24h-Post	3.55 ± 0.59	3.90 ± 0.21^{+}	3.50 ± 0.57


A
Fatigue (AU)
1
2
3
4
5
Low
Moderate
High
Condition Intensity
*
*
Pre
Post
24 h Post
B
Readiness to Train (AU)
0
1
2
3
4
5
Low
Moderate
High
Condition Intensity
*
C
General Soreness (AU)
1
2
3
4
5
Low
Moderate
High
Condition Intensity
*
D
Total Wellness (AU)
10
15
20
25
30
Low
Moderate
High
Condition Intensity


A
Cycle-Ergometer Peak Power (Watts)
1600
1400
1200
1000
800
600
^
^
^
Pre
Post
24 h Post
Low
Moderate
High
Condition Intensity
B
Counter-movement Jump (CM)
60
50
40
30
20
Low
Moderate
High
Condition Intensity
C
Maximal Voluntary Torque (Nm)
350
300
250
200
150
100
#
+ +
#
+ +
#
Low
Moderate
High
Condition Intensity
D
Voluntary Activation (%)
100
90
80
70
60
^
*
Low
Moderate
High
Condition Intensity