# Relationships between training load, sleep duration, and daily wellbeing and recovery measures in youth athletes

Running head: Training load, sleep and wellbeing relationships

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**Abstract**

**Purpose:** To assess the relationships between training load, sleep duration and three daily wellbeing, recovery and fatigue measures in youth athletes. **Methods:** Fifty-two youth athletes completed three maximal countermovement jumps (CMJ), a daily wellbeing questionnaire (DWB), the Perceived Recovery Status scale (PRS), and provided details on their previous day's training loads (training) and self-reported sleep duration (sleep) on four weekdays over a seven week period. Partial correlations, linear mixed models and magnitude-based inferences were used to assess the relationships between the predictor variables (training; sleep) and the dependent variables (CMJ; DWB; PRS). **Results:** There was no relationship between CMJ and training ($r$=-0.09; ±0.06) or sleep ($r$=0.01; ±0.06). The DWB was correlated with sleep ($r$=0.28; ±0.05, *small*), but not training ($r$=-0.05; ±0.06). The PRS was correlated with training ($r$=-0.23; ±0.05, *small*), but not sleep ($r$=0.12; ±0.06). The DWB was sensitive to low sleep($d$=-0.33; ±0.11) relative to moderate, PRS was sensitive to high ($d$=-0.36; ±0.11) and low ($d$=0.29; ±0.17) training relative to moderate. **Conclusions:** The PRS is a simple tool to monitor the training response, but DWB may provide a greater understanding of the athlete's overall wellbeing. The CMJ was not associated with the training or sleep response in this population.

## Introduction

It is well established that in order to adapt to a training stimulus, an optimal balance between training stress and recovery is required (39). Failure to provide appropriate periods of recovery between training sessions and within programmes can lead to lowered training capacity (9, 22) or increased incidence of injury, illness and overtraining (8, 25, 34). As a consequence of these negative outcomes, it has become increasingly common for coaches and sport scientists to monitor an athlete's response to training using various fatigue measures including wellbeing questionnaires and measures of neuromuscular fatigue (e.g. countermovement jumps (CMJ)). With an increasing professionalisation of sport at younger ages, these methods have recently been applied within adolescent and collegiate/high school youth sport athletes (7, 29, 37).

Subjective daily wellbeing questionnaires have become increasingly prominent as a quick and easy method of understanding an athlete's readiness to train (12, 42) and can incorporate questions surrounding an athlete's sleep, stress levels, mood, fatigue, appetite and muscle soreness (10, 24, 29, 47). There is a large body of research demonstrating the change in wellbeing questionnaires over the course of a pre- or full season period (7, 24, 29). For example, perceptions of wellbeing have been shown to fall by at least one z-score the day after a rugby league or American football match, but do not recover to baseline levels for at least four days after the match (7, 24). Furthermore, research has shown that a drop in perceptions of wellbeing can lead to reductions in external training load output in elite adult soccer and Aussie Rules players (9, 22). However, whilst this research is valuable, it fails to quantify the association between training load and wellbeing in adolescent athletes. This information is particularly valuable in youth sport settings when considering the unique set of academic, social and maturational circumstances they must circumnavigate and the impact these may have on their wellbeing alongside their sporting endeavours (28).

Alongside perceptions of wellbeing, it may be useful to collect measures objectively or subjectively evaluating an athlete's fatigue and recovery status. Consequently, alternative monitoring methods (e.g. the Perceived Recovery Status Scale (PRS; 16) or CMJ) should be considered. The PRS is a 0-10 scale, where athletes are asked to rate their recovery using descriptors anchored to numerical values similar to the Borg category-ratio 10 scale (6). It has shown good sensitivity to both aerobic and resistance based exercise protocols (19, 45), but no study exists within applied sport settings. It is important that this environment is considered so its association with uncontrolled training loads can be confirmed. The CMJ, a surrogate measure of neuromuscular fatigue, has received significant support within the literature as a fatigue measure (24, 37, 40, 47). However, although recent studies have demonstrated its association with training load in elite adult soccer players on both a jump mat (47) and a force plate (40), no relationship was found when it was tested in elite youth soccer players, possibly due to the basic statistical methods used (21). Despite conflicting findings between the studies, it is work in professional soccer using a force plate (40) which provides the most practically interesting findings. This work compared high, medium and low training loads showing expected changes in CMJ metrics over the following 90 hours. As would be expected, medium and high loads exhibited greater changes than low loads, showing the association between training loads and CMJ, and a replication of this more advanced statistical analysis could be beneficial to show the relationship between differing levels of training load and CMJ, PRS and daily wellbeing measures in a youth sport athlete cohort.

In addition to training load, sleep has previously shown relationships with changes in mood, and injury and illness risk, as well as being implicated with the overtraining syndrome (3, 25, 26, 30). Previous studies have eschewed the use of self-reported sleep duration as a predictor of outcome measures due to its lack of validity compared to actigraphy (11, 18), instead using a measure of sleep quality within their wellbeing questionnaires (1, 10, 37, 47). However, the validity of subjective sleep quality measures has also been questioned when compared to objective measures (17). Furthermore, as some individuals complain of poor sleep quality when their objective sleep measures are normal and others indicate they have had good quality sleep when their objective sleep measures suggest otherwise (17), it is arguable that the individual's perceptions of sleep, in terms of duration and quality, may be more important than the objective measure itself. Isolating the impact of sleep as a sleep quality subscale also ensures it is difficult to identify whether the training load itself or the circumstances arising from the prescribed training load (e.g. early/late training times and travel time to/from training sessions affecting sleep habits) result in changes in perceptions of sleep quality and wellbeing. The inclusion of self reported sleep duration in analyses could therefore add to the understanding of factors affecting different wellbeing measures, particularly as some of these measures already include sleep quality subscales but no information relating to sleep duration.

In summary, there is currently limited research considering the associations between daily wellbeing and recovery measures (e.g. wellbeing questionnaires, PRS and CMJ), and training loads and sleep duration. Consequently, the aim of this study was to assess the relationships between changes in a daily wellbeing questionnaire, the PRS scale and the CMJ, and changes in training loads and self-reported sleep duration in youth sport athletes. A secondary aim of the study was to provide practically meaningful information with regards to the associations between the measures.

## Methods

### *Participants*

Fifty-two youth sport athletes aged 16-18 years (age 17.3 ± 0.6 years, height 173.0 ± 18.2 cm, body mass 73.7 ± 12.6 kg) were recruited for this study from a local independent school in the United Kingdom (UK). The athletes were part of the school's sport scholarship programme and competed in basketball (n=1), cricket (n=5), football (n=10), hockey (n=8), netball (n=9), rugby (n=17), swimming (n=2). All athletes had previously competed at academy level or above and were now club/school (n=31), academy (n=6), county/regional (n=12) or international (n=3) standard in their respective sports. Forty participants competed in sports outside of school in addition to their academic sporting commitments. Ethics approval was granted by the University Ethics Committee and written informed consent was provided by all participants and their parents prior to the study.

### *Study Procedures*

The study was conducted during a seven-week period in April and May at the end of the UK school academic year. From Monday to Thursday inclusive, participants completed an online Google Docs

(Google Forms, Google, CA, USA) questionnaire every morning prior to their first training session of the day. This included a daily wellbeing questionnaire related to sleep quality, fatigue, muscle soreness, stress and mood (DWB; 22) totalled to a score out of 25, the PRS (19), self-reported sleep duration (in hours) and 24 hour training load recall.

The between day reliability, as a coefficient of variation, and smallest worthwhile change of DWB and PRS were calculated using two time points 7 days apart. Each datum point was preceded by a day of rest and was selected so that the difference in sleep duration was as small as possible. The between-day reliability for DWB was 11.7% and PRS was 8.5%. The smallest worthwhile changes were 6.2% and 4.9% respectively for DWB and PRS. Participants rated each session for the 24 hour training load using the Borg category ratio-10 scale (6), choosing the respective descriptor. The descriptor was converted to the appropriate RPE number and multiplied by the session duration (also provided by the participant) to provide the sessional RPE (s-RPE) and the sum of all s-RPE's on a single day gave the daily training load. The temporal robustness of the s-RPE method has previously been confirmed over 24 hours (32, 44).

Following completion of the questionnaire and a short warm up consisting of leg swings, lunges, squats and two practice CMJs, participants were asked to execute three maximal CMJs on four weekdays, each separated by 1 minute of rest consistent with previous protocols (38). Participants began with their legs fully extended, their feet at a self-selected width and their hands on their hips. They were then instructed to squat down and jump as high as they could in a fluid, countermovement motion. The depth of the countermovement was self-selected. Participants were instructed to keep their legs extended in flight and to land with their legs straight. Jump height was measured in centimetres using the Optojump system (Microgate, Bolzano, Italy). Participants were familiar with the CMJ protocol, which has previously been shown to have a typical error of 2.8% and smallest worthwhile change of 3.9% in this population (43). Due to the poor face validity of the CMJ test in a swimming population (23), the swimmers (n=2) did not take part in this test.

*Statistical Analyses*

For statistical analysis, CMJ jump height underwent natural log transformation to reduce bias as a result of non-uniformity of error. Initially, partial correlations were used to assess the linear relationship between the wellbeing measures and training load and sleep duration. Athlete, Sport, week, weekday, training load and sleep duration were included in all correlations. Athlete and Sport referred to the ID of the athlete and the sport they played. Week referred to the week of the study (1-7), weekday referred to the day of the week (Monday to Thursday). A linear mixed model was also performed to provide a practical interpretation of the difference between the effect of training load and sleep duration on wellbeing measures. Training loads and sleep duration were separated into three groups according to each athlete's individual z-scores for the day in question: Low (training load or sleep duration < -1z); Moderate (-1z < training load or sleep duration <1z); High (training load or sleep duration >1z). It was therefore possible for an athlete to be classified as high training load, but low sleep duration on one day, but moderate training load and high sleep duration on another day, or any combination of the three groupings. Training load, sleep duration, sport, week and weekday were added to the model as fixed effects, athlete was added as a random effect. Pairwise comparisons showed the magnitude of difference between the groups, with the moderate group used as the reference for visualisation purposes. Data were analysed using SAS University Edition (SAS Institute, Cary, NC).

Results were analysed for practical significance using magnitude-based inferences (16). The threshold for a change to be considered practically important (the smallest worthwhile change) was set as 0.2 x observed between participant standard deviation, based on Cohen's *d* effect size (ES) principle (15). Thresholds ES were set as: 0.2 *small;* 0.6 *moderate;* 1.2 *large*, 2.0 *very large.* Thresholds for correlations (*r*) were set as: 0.1 *small;* 0.3 *moderate;* 0.5 *large;* 0.7 *very large;* 0.9 *almost perfect.* The probability that the magnitude of change was greater than the smallest worthwhile change was rated as: <0.5% *almost certainly not*; 0.5-5% *very unlikely*; 5-25% *unlikely*; 25-75% *possibly*; 75-95% *likely*; 95-99.5% *very likely*; >99.5% *almost certainly* (16). All data are reported as mean ± standard deviation. ES and correlations are reported ES and *r*; ± 90% confidence intervals, and the direction of the association (positive or negative) is reported in the text.

**Results**

. Table 1 provides descriptive characteristics for the training load and sleep length zones.

** INSERT TABLE 1 HERE **

Table 2 shows the partial correlations between the wellbeing measures of DWB, PRS and CMJ and training load and sleep duration. It shows a *small* positive correlation between DWB and sleep duration ($r$=0.28; ± 0.05) and a *small* negative effect of training load on PRS ($r$=-0.23; ±0.05). All other effects were *trivial* or did not reach the pre-determined threshold for meaningful inference.

** INSERT TABLE 2 HERE **

Figures 1 and 2 show pairwise comparisons for the effect of differing quantities of training load and sleep duration on DWB and PRS. The CMJ was not plotted in this way due to its *trivial* relationship with training load and sleep duration (Table 2). DWB showed a negative trend with training load, but as both differences were *trivial*, this was not deemed practically meaningful. A *small* positive effect of low training load on PRS is shown ($d$=0.29; ±0.17), along with a *small* negative effect of high training load ($d$=-0.36; ±0.11) relative to moderate. There was a *small* negative effect of low sleep duration on DWB ($d$=-0.33; ±0.11), but the questionnaire was shown not associated with high sleep durations. The PRS showed no relationship or trend with sleep duration.

** INSERT FIGURES 1 & 2 HERE **

**Discussion**

The aims of this study were to assess the relationships between a DWB questionnaire, the PRS scale and the CMJ with the previous day's training load and self-reported sleep duration and to provide practical information relating to these relationships in youth sport athletes. The results indicated that there was no relationship between DWB and training loads, but DWB was associated with low sleep duration, whereas PRS was associated with high and low training loads but not sleep duration. CMJ showed no relationship with training load or sleep duration.

The key finding of this study is that DWB showed no relationship with training load. These results conflict with research in elite adult team sport athletes indicating that training load does affect DWB (1, 10, 47), but agree with findings in adolescent athletes where training load was not related to the recovery-stress balance as measured by the Recovery Stress Questionnaire for Athletes (13). It is possible that this is due to a difference in the relative intensity of stressors between the two populations. Adolescent athletes have a unique set of social, educational and maturational circumstances to navigate (28), which may be of greater relative importance to their wellbeing than training for their sport alone. In addition to these other stressors, the intensity of training at an adolescent level is significantly lower than at the elite adult level (2, 4, 35, 36). The results may indicate that academic and social stresses are of greater importance to adolescent athletes' wellbeing than training load, but more research is needed to confirm the predictive qualities of these stressors on the youth athletes' wellbeing.

The association of sleep duration, particularly low levels of sleep, with DWB at the expense of training load is unique to this study. Although it is well known that sleep deprivation results in lower mood (30) and that increased training loads are linked with reduced sleep (41), no study has yet controlled for the effects of sleep duration on DWB when assessing the impact of other predictors. The average sleep duration of 7.3 hours reported in this study falls below the National Sleep Foundation's recommendations of 8-10 hours per night for adolescents (14). Given that these guidelines don't account for the extra sleep required by youth sport athletes relative to the average population (5), it is possible that insufficient sleep, and by extension recovery, is a greater issue for youth athletes than the training load experienced. This, in combination with the academic and social stressors influencing sleep duration (31) could explain why DWB has a greater association with sleep than training load.

Our results showed a small relationship between PRS and training load, but no association with sleep duration. This is the first study to consider the PRS in a practical setting and progresses the literature from previous laboratory based studies (19, 45). The results indicate that PRS is sensitive to the training loads encountered by youth sport athletes, possibly because it does not consider as many factors as DWB and solely asks "*how recovered do you feel?*". The PRS may therefore be a simple method of monitoring the training load response and prescribing training. Unlike the DWB with sleep duration, the PRS shows an almost perfect linear relationship with training load as high and low training loads fall outside the smallest worthwhile change of the moderate training load group (Figure 1). The lack of association between PRS and sleep duration could indicate that the PRS is primarily affected by perceptions of physical and mental fatigue rather than the mental disturbances caused by changes in sleep duration (30) or the other stressors associated with this age range (28). Consequently, the combination of DWB and PRS provides an excellent starting point as a monitoring tool by which the effects of stressors on both physical and mental status can be considered in this population. However, it should be noted that only DWB and PRS were considered as subjective questionnaires within this study and other questionnaires may prove similarly effective as monitoring tools.

Our finding that CMJ was not related to training load conflicts with the literature showing training load to result in a decrease in CMJ in elite adult athletes (40, 47), but agrees with that in elite youth soccer players (21). It has previously been argued that adolescent athletes train at a lower intensity than elite athletes (2, 4, 35, 36), which could result in lower neuromuscular fatigue and a reduced need for a neuromuscular fatigue test such as the CMJ. The agreement of our results with a previous study in a similar cohort using the same equipment (21) provides further evidence within the literature that training load (within the ranges presented in this study) does not affect CMJ performance in this population. The lack of association between CMJ and sleep duration contradicts previous literature suggesting that sleep deprivation and extension can have positive and negative effects on neuromuscular performance respectively (20, 46). However, given the training stimulus in this study may not have been intense enough to reduce neuromuscular function and the sleep duration shown in this study were reasonably uniform in nature, it is unsurprising that there was no difference in neuromuscular recovery attributable to the duration of sleep experienced. Alternatively, the wide variability in the effect of training load on CMJ ($r$ = 0.09; ± 0.06) could be due to the inherent variation in motivation shown between and within participants over the duration of this study, which may have resulted in participants not always providing their best effort. Regardless, our results indicate that CMJ is not responsive to training load or sleep length in this population.

*Limitations*

Although our results add to the literature, they are not without their limitations. The primary limitation of the study being that it took place on four weekdays, which skews the distribution of sleep durations in favour of low sleep as evidenced by the number of observations in the low sleep group (n=88) *vs.* those in the high sleep group (n=22). Future studies should attempt to collect data over all seven week days so that a more complete understanding can be obtained. In addition to this, the use of self-reported sleep duration could be criticised. Self-reported sleep durations can be overestimated by as much as 1.5 hours (18), which should be considered if they are to be used in practice. It should also be noted that the use of sleep duration alone provides little understanding relating to the quality of the sleep. Although this measure was collected as part of DWB in line with current research (24, 47), future research may wish to consider removing it from DWB and using it as a predictive measure alongside sleep duration, given its known impact of wellbeing measures (33). From a training load perspective, for the purposes of this study all training loads were grouped together to provide a daily training load. It has previously been suggested that there may be an additive effect of match stress (27), and there are likely to be different responses to aerobic and resistance exercise so a future study may wish to isolate different types of training and assess their effect on wellbeing to enhance understanding in the area. Finally, and perhaps most importantly, this study provides no understanding of the impact on competitive performance in this population. Previous research has shown that a decline in perceptions of wellbeing does impact on training performance in elite athletes (9, 22), however such an effect may not be present in youth athletes due to their unique circumstances (28). Future research should therefore attempt to quantify whether there is a relationship between perceptions of wellbeing and competitive performance in youth sport athletes.

Altogether, our results provide support for the use of both a DWB questionnaire and PRS scale when monitoring the youth sport athlete. The PRS showed a greater association with training load than either DWB or CMJ, but only provides an understanding of how recovered the athlete feels. The DWB on the other hand was not related to training load, but appears to provide a greater understanding of the athlete's overall state of wellbeing and is associated with low sleep durations. Consequently, the use of both questionnaires provides an understanding of the athlete's readiness to train. Our results do not recommend the use of CMJ as a monitoring strategy in this population. Future research should confirm the results of this study over a longer period of time, including weekends, so that the effect of sleep duration on both questionnaires can be fully elucidated. Furthermore, research should consider how the predictors of training load and sleep duration interact with the response measures of DWB and PRS in an attempt to predict outcome measures of injury and illness incidence, and athletic development.

**References**


(1) Buchheit M, Racinais S, Bilsborough JC, et al. Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. *J Sci Med Sport* 2013; 16: 550–555.

(2) Chandler PT, Pinder SJ, Curran JD, et al. Physical demands of training and competition in collegiate netball players. *J Strength Cond Res* 2014; 28: 2732–2737.

(3) Cohen S, Doyle WJ, Alper CM, et al. Sleep habits and susceptibility to the common cold. *Arch Intern Med* 2009; 169: 62–67.

(4) Cormack SJ, Smith RL, Mooney MM, et al. Accelerometer load as a measure of activity profile in different standards of netball match play. *Int J Sports Physiol Perform* 2014; 9: 283–291.

(5) Davenne D. Sleep of athletes – problems and possible solutions. *Biol Rhythm Res* 2009; 40: 45–52.

(6) Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res* 2001; 15: 109–15.

(7) Fullagar HH, Govus A, Hanisch J, et al. The time course of perceptual recovery markers following match play in Division 1-A collegiate American footballers. *Int J Sports Physiol Perform*; epub ahead of print.

(8) Gabbett TJ, Whyte DG, Hartwig TB, et al. The relationship between workloads, physical performance, injury and illness in adolescent male football players. *Sport Med* 2014; 44: 989–1003.

(9) Gallo TF, Cormack SJ, Gabbett TJ, et al. Pre-training perceived wellness impacts training output in Australian football players. *J Sports Sci* 2016; 34: 1445–1451.

(10) Gastin PB, Meyer D, Robinson D. Perception of wellness to monitor adaptive responses to training and competition in elite Australian Football. *J Strength Cond Res* 2013; 27: 2518–2526.

(11) Girschik J, Fritschi L, Heyworth J, et al. Validation of self-reported sleep against actigraphy. *J Epidemiol* 2012; 22: 462–468.

(12) Halson SL. Monitoring training load to understand fatigue in athletes. *Sport Med* 2014; 44: S139-147.

(13) Hartwig TB, Naughton G, Searl J. Load, stress, and recovery in adolescent rugby union players during a competitive season. *J Sports Sci* 2009; 27: 1087–1094.

(14) Hirshkowitz M, Whiton K, Albert SM, et al. National Sleep Foundation’s sleep time duration recommendations: Methodology and results summary. *Sleep Heal* 2015; 1: 40–43.

(15) Hopkins WG. Measures of reliability in sports medicine and science. *Sport Med* 2000; 30: 1–15.

(16) Hopkins WG, Marshall SW, Batterham AM, et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; 41: 3–12.

(17) Krystal AD, Edinger JD. Measuring sleep quality. *J Sleep Med* 2008; 9: S10–S17.

(18) Lauderdale DS, Knutson KL, Yan LL, et al. Sleep duration: How well do self-reports reflect objective measures? The CARDIA Sleep Study. *Epidemiology* 2008; 19: 838–845.

(19) Laurent CM, Green JM, Bishop PA, et al. A practical approach to monitoring recovery: Development of a perceived recovery status scale. *J Strength Cond Res* 2011; 25: 620–628.

(20) Mah CD, Mah KE, Kezirian EJ, et al. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep* 2011; 34: 943–950.

(21) Malone JJ, Murtagh CF, Morgans R, et al. Countermovement jump performance is not affected during an in-season training microcycle in elite youth soccer players. *J Strength Cond Res* 2015; 29: 752–757.

(22) 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*; epub ahead of print.

(23) McGuigan M. *Monitoring training and performance in athletes*. Champaign, IL: Human Kinetics, 2017.

(24) McLean BD, Coutts AJ, Kelly V, et al. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sports Physiol Perform* 2010; 5: 367–383.

(25) Meeusen R, Duclos M, Foster C, 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 Sport Exerc* 2013; 45: 186–205.

(26) Milewski MD, Skaggs DL, Bishop GA, et al. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. *J Pediatr Orthodpedics* 2014; 34: 129–133.

(27) Montgomery PG, Hopkins WG. The effects of game and training loads on perceptual responses of muscle soreness in Australian Football. *Int J Sports Physiol Perform* 2013; 8: 312–318.

(28) Mountjoy M, Armstrong N, Bizzini L, et al. IOC consensus statement: 'Training the elite child athlete'. *Br J Sports Med* 2008; 42: 163–164.

(29) Noon MR, James RS, Clarke ND, et al. Perceptions of well-being and physical performance in English elite youth footballers across a season. *J Sports Sci* 2015; 33: 2106–2115.

(30) Oginska H, Pokorski J. Fatigue and mood correlates of sleep length in three age-social groups: School children, students, and employees. *Chronobiol Iternational* 2006; 23: 1317–1328.

(31) Owens J. Insufficient sleep in adolescents and young adults: An update on causes and consequences. *Pediatrics* 2014; 134: e921–e932.

(32) Phibbs P, Roe G, Jones B, et al. Validity of daily and weekly self-reported training load measures in adolescent athletes. *J Strength Cond Res* 2017; 31: 1121–1126.

(33) Pilcher JJ, Ginter DR., Sadowsky B. Sleep quality versus sleep quantity: Relationships between sleep and measures of health, well-being and sleepiness in college students. *J Psychosom Res* 1997; 42: 583–596.

(34) Putlur P, Foster C, Miskowski JA, et al. Alteration of immune function in women collegiate soccer players and college students. *J Sport Sci Med* 2004; 3: 234–243.

(35) Read D, Jones B, Phibbs P, et al. Physical demands of representative match play in adolescent rugby union. *J Strength Cond Res* 2017; 31: 1290–1296.

(36) Roberts SP, Trewartha G, Higgitt RJ, et al. The physical demands of elite English rugby union. *J Sports Sci* 2008; 26: 825–833.

(37) Roe G, Darrall-Jones JD, Till K, et al. Preseason changes in markers of lower body fatigue and performance in young professional rugby union players. *Eur J Sport Sci* 2016; 16: 981–988.

(38) Roe G, Darrall-Jones JD, Till K, et al. Between-day reliability and sensitivity of common fatigue measures in rugby players. *Int J Sports Physiol Perform* 2016; 11: 581–586.

(39) Rowbottom DG. Periodization of training. In: Garrett WE, Kirkendall DT (eds) *Exercise and Sport Science*. Philadelphia: Lippincott, Williams and Wilkins, 2000, pp. 499–514.

(40) Rowell AE, Aughey RJ, Hopkins WG, et al. Identification of sensitive measures of recovery following external load from football match play. *Int J Sports Physiol Perform*; epub ahead of print.

(41) Sargent C, Lastella M, Halson SL, et al. The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiol Int* 2014; 31: 1160–1168.

(42) Saw AE, Main LC, Gastin PB. Monitoring athletes through self-report: Factors influencing implementation. *J Sport Sci Med* 2015; 14: 137–146.

(43) Sawczuk T, Jones B, Scantlebury S, et al. Between-day reliability and usefulness of a fitness testing battery in youth sport athletes: Reference data for practitioners. *Meas Phys Educ Exerc Sci*; epub ahead of print

(44) Scantlebury S, Till K, Sawczuk T, et al. The validity of retrospective session-rating of perceived exertion to quantify training load in youth athletes. *J Strength Cond Res*; epub ahead of print.

(45) Sikorski EM, Wilson JM, Lowery RP, et al. Changes in perceived recovery status scale following high-volume muscle damaging resistance exercise. *J Strength Cond Res* 2013; 27: 2079–2085.

(46) Skein M, Duffield R, Minett GM, et al. The effect of overnight sleep deprivation after competitive rugby league matches on p;ostmatch physiological and perceptual recovery. *Int J Sports Physiol Perform* 2013; 8: 556–564.

(47) 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* 2017; 12: S2107–S2113.

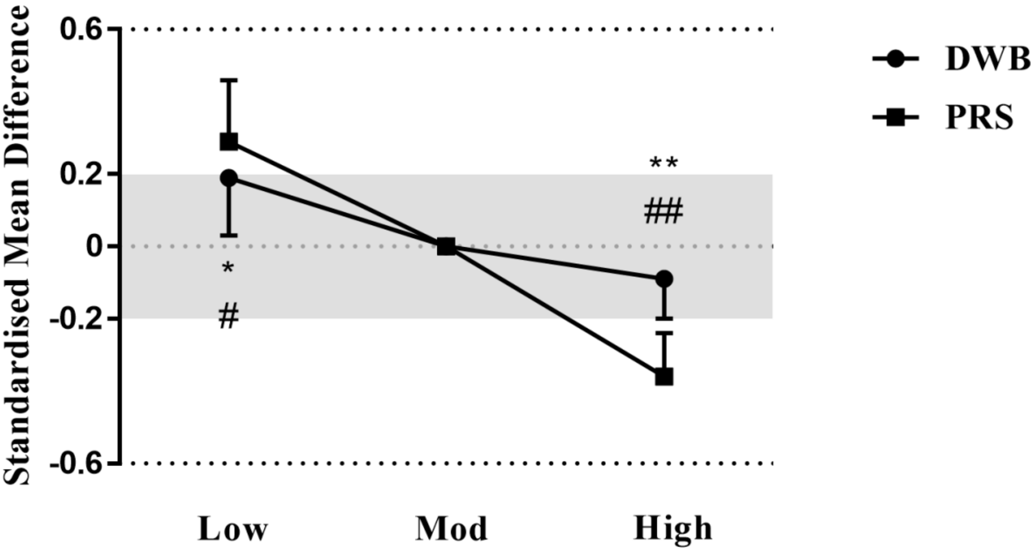


**Figure 1:** Visual representation of pairwise comparisons for the differing effect of high, moderate and low training loads on DWB and PRS. Data are presented as mean difference relative to moderate training load ± 90% confidence intervals. Shaded area represents smallest worthwhile change . Asterixes and hashtags denote likelihood that the difference in effect is greater than the smallest worthwhile change: * likely; ** very likely for DWB; # likely; ## very likely for PRS.

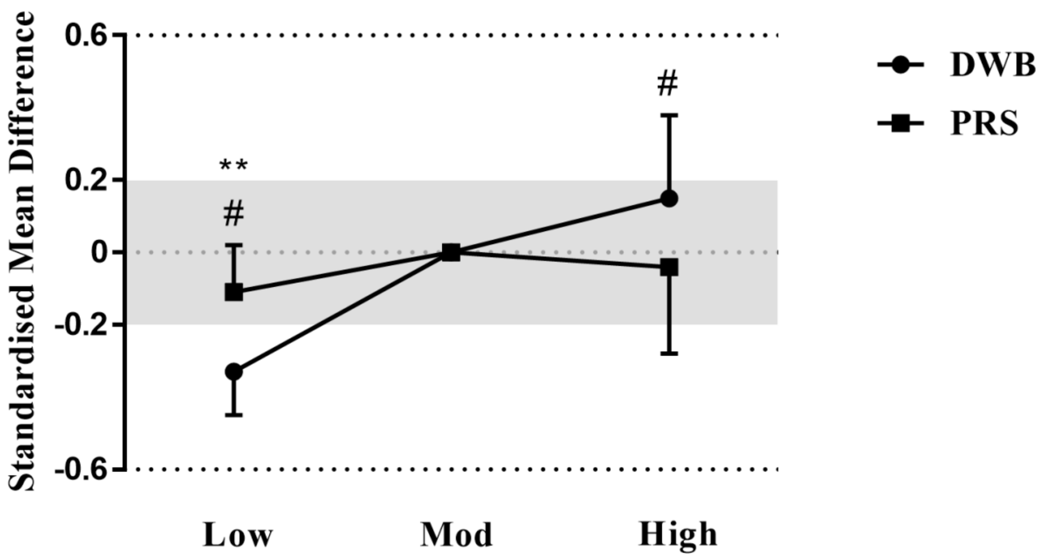


**Figure 2:** Visual representation of pairwise comparisons for the differing effect of high, moderate and low sleep duration on DWB and PRS. Data are presented as mean difference relative to moderate sleep length ± 90% confidence intervals. Shaded area represents smallest worthwhile change. Asterixes and hashtags denote likelihood that the difference in effect is greater than the smallest worthwhile change: ** very likely for DWB; # likely for PRS.

**Table 1:** Descriptive statistics for training load and sleep duration groups as independent variables (IV) based on individual z-scores (z)

| | **Low (IV <-1z)** | **Moderate (-1z< IV <1z)** | **High (IV >1z)** |
|---|---|---|---|
| **Training Load (AU)** | | | |
| n | 73 | 628 | 124 |
| Minimum | 0 | 0 | 300 |
| Maximum | 380 | 1235 | 2450 |
| Median | 0 | 180 | 627.5 |
| Interquartile Range | 0 | 300 | 397.5 |
| **Sleep Duration (hours)** | | | |
| n | 88 | 709 | 28 |
| Minimum | 3 | 5 | 9 |
| Maximum | 10 | 11 | 13 |
| Median | 6 | 7 | 10 |
| Interquartile Range | 2 | 1 | 1 |

**Table 2:** Partial correlation coefficients, directions, magnitudes and descriptors for the effect of training load and sleep length on DWB, PRS and CMJ. Data are presented as mean ± 90% confidence intervals.

| | **Correlation Coefficient** | **Magnitude** | **Descriptor** |
|---|---|---|---|
| **DWB** | | | |
| Training Load | -0.05; ± 0.06 | *Trivial* | *Likely* |
| Sleep Duration | 0.01; ± 0.06 | *Trivial* | *Very Likely* |
| **PRS** | | | |
| Training Load | -0.23; ± 0.05 | *Small* | *Most Likely* |
| Sleep Duration | 0.12; ± 0.06 | *Small* | *Possibly* |
| **CMJ** | | | |
| Training Load | -0.09; ± 0.06 | *Trivial* | *Possibly* |
| Sleep Duration | 0.01; ± 0.06 | *Trivial* | *Very Likely* |