The influence of training load, exposure to match play and sleep duration on daily wellbeing measures in youth athletes

Running head: Influence of training load and sleep on daily wellbeing

Keywords: Monitoring; recovery; athlete wellness, sleep, training load

Thomas Sawczuk[1,2], Ben Jones[1,2,3,4,5], Sean Scantlebury[1,2], Kevin Till[1,3,5]

[1] Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, United Kingdom

[2] Queen Ethelburga's Collegiate, Thorpe Underwood, York, United Kingdom

[3] Yorkshire Carnegie Rugby Club, Headingley Carnegie Stadium, Leeds, United Kingdom

[4] The Rugby Football League, Red Hall, Leeds, United Kingdom

[5] Leeds Rhinos Rugby Club, Headingley Carnegie Stadium, Leeds, United Kingdom

Corresponding Author:
Thomas Sawczuk
Room G03, Macaulay Hall;
Institute for Sport, Physical Activity and Leisure, Centre for Sports Performance;
Leeds Beckett University, Headingley Campus;
West Yorkshire;
LS6 3QS
Email: t.sawczuk@leedsbeckett.ac.uk
Phone: (0044) 7530 945555

Abstract

This study assessed the influence of training load, exposure to match play and sleep duration on two daily wellbeing measures in youth athletes. Forty-eight youth athletes (age 17.3 ± 0.5 years) completed a daily wellbeing questionnaire (DWB), the Perceived Recovery Status scale (PRS), and provided details on the previous day's training loads (TL) and self-reported sleep duration (sleep) every day for 13 weeks ($n = 2727$). A linear mixed model assessed the effect of TL, exposure to match play and sleep on DWB and PRS. An increase in TL had a *most likely small* effect on muscle soreness (d=-0.43±0.10) and PRS (d=-0.37±0.09). Match play had a *likely small* additive effect on muscle soreness (d=-0.26±0.09) and PRS (d=-0.25±0.08). An increase in sleep had a *most likely moderate* effect on sleep quality (d=0.80±0.14); a *most likely small* effect on DWB (d=0.45±0.09) and fatigue (d=0.42±0.11); and a *likely small* effect on PRS (d=0.25±0.09). All other effects were *trivial* or did not reach the pre-determined threshold for practical significance. The influence of sleep on multiple DWB subscales and the PRS suggests that practitioners should consider the recovery of an athlete alongside the training stress imposed when considering deviations in wellbeing measures.

Abstract word count: 197

Total word count: 4,406

Introduction

It is essential that an optimal balance between stress and recovery is reached when constructing athletic development programmes (Rowbottom, 2000). The stress-recovery balance dictates that when a body is subjected to a stressor (e.g. training load, examination stress or social pressures), an appropriate amount of recovery time (e.g. sleep) is required to maintain equilibrium (Kellmann, 2010). In sport, failure to maintain the stress-recovery balance can result in de-training, injury, illness or overtraining (Hulin et al., 2014; Meeusen et al., 2013; Putlur et al., 2004). Consequently, it has become commonplace to monitor an athlete's stress-recovery balance using subjective daily wellbeing questionnaires (DWB; Saw, Main, & Gastin, 2015). These questionnaires, as self-report measures, are now widespread in professional adult sport due to their inexpensiveness, time efficiency and ease of analysis (Saw et al., 2015; Saw, Main, & Gastin, 2016), but are also becoming increasingly prominent at youth level (Noon, James, Clarke, Akubat, & Thake, 2015; Sawczuk, Jones, Scantlebury, & Till, 2018). However, the stress-recovery balance at youth level may vary in response to training stressors as athletes attempt to cope with educational (e.g. academic examinations), maturational (e.g. hormonal changes) and social (e.g. pressure to succeed, relationships and peer pressure) demands alongside their sporting endeavours (Mountjoy et al., 2008; Siesmaa, Blitvich, & Finch, 2011). In order for wellbeing questionnaires to be fit for purpose, it is important that they are responsive to the stress and recovery experienced by the athlete. In sport, the primary stressor imposed upon an athlete by the coaching staff, aimed at enhancing their athletic development, is the training stimulus, whereas the primary mechanism of recovery is sleep (Halson, 2014a, 2014b). However, whilst there is a growing body of literature considering the influence of training load on DWB (Buchheit et al., 2013; Thorpe et al., 2017), studies considering their relationship with sleep are scarce (Sawczuk et al., 2018).

The influence of training load on overall DWB scores appears surprisingly contentious given their widespread use in sport (Saw et al., 2015). Buchheit and colleagues (2013) found a DWB and all its individual subscales (i.e. measures of fatigue, muscle soreness, sleep quality, stress and mood) to be related to training load in Australian Rules football players during the pre-season phase. However, other studies in Australian Rules football players (Gallo, Cormack, Gabbett, & Lorenzen, 2017) and youth athletes (Sawczuk et al., 2018) have argued that the overall DWB score is not influenced by the previous day's workload. It is possible that the difference between these studies is due to the training loads present. Buchheit and colleagues (2013) reported a weekly training load of over 10,000 AU in their study, whereas both studies reporting no change had weekly training loads of around 1,750 AU (Gallo et al., 2017; Sawczuk et al., 2018). Furthermore, only Buchheit and colleagues (2013) provided a DWB subscale analysis which showed all subscales to have a *small* association with training load. Given that very high training loads are believed to affect mood and stress prior to the onset of the overtraining syndrome (Meeusen et al., 2013) and neither Gallo and colleagues (2017) nor Sawczuk and colleagues' (2017) studies included very high training loads, it is possible that a masking effect between subscales occurred within the studies showing no relationship between DWB and training load. Therefore, fatigue, muscle soreness and sleep quality may have been affected by training load but a lack of association with other subscales could have blunted the overall response. Previous studies have shown that individual subscales such as fatigue (Thorpe et al., 2015, 2017), muscle soreness (Montgomery & Hopkins, 2013), and the PRS (Sawczuk et al., 2018) may be affected by training load and exposure to match play at training loads between 1,750 and 2,000 AU, supporting this hypothesis. However, none of these studies analysed the effect of these training loads on mood or stress subscales. A study considering the effect of moderate weekly training loads (circa 2,000 AU per week), including exposure to match play, on the overall DWB score and all individual subscales, and a comparison with the PRS, a standalone scale shown to be sensitive to training loads (Sawczuk et al., 2018), is therefore merited.

In order to recover from the training and match stimuli encountered by athletes, it is important that sleep is optimised (Halson, 2014b; Tuomilehto et al., 2017). Previous research has indicated that sleep can affect sporting performance (Fullagar et al., 2015; Mah, Mah, Kezirian, & Dement, 2011), risk of illness (Cohen, Doyle, Alper, Janicki-Deverts, & Turner, 2009; Prather, Janicki-Deverts, Hall, & Cohen, 2015) and wellbeing measures (Oginska & Pokorski, 2006). Despite this evidence showing the importance of sleep, previous studies have avoided the use of self-reported sleep duration as a predictor of changes in wellbeing measures due to its perceived lack of validity when compared to actigraphy measures (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). However, it has recently become apparent that in athletic populations self-reported sleep duration is a valid measure when compared to actigraphy (Caia et al., 2017; Kölling, Endler, Ferrauti, Meyer, & Kellmann, 2016), although it maintains its systematic bias of overestimating sleep duration by around 1 hour. These new findings, alongside suggestions that perceptions of sleep quality are not always congruent with objective measures (Krystal & Edinger, 2008), provide rationale for the use of self-reported sleep duration as a predictor of changes in wellbeing. To date, the only study to have considered the influence of sleep duration on a sport specific wellbeing measure found DWB to be related to short, but not extended, sleep durations and found no relationship with the PRS (Sawczuk et al., 2018). However, the study only took place on four weekdays, which may not be representative of a youth athlete population as participants would likely have had to be at school by 8.30am on those weekdays, whereas their sleep durations may not be similarly restricted at weekends. Furthermore, the inclusion of a sleep quality measure within the overall DWB score could have skewed the true relationship, but an individual subscale analysis was not provided in the study. Therefore, there is scope for a study considering all seven days, in which the influence of self-reported sleep length on DWB, its individual subscales and the PRS is considered, alongside training loads and match stress. Consequently, the aim of this study was to assess the influence of training load, exposure to match play and self-reported sleep duration on a DWB, its individual subscales (i.e. muscle soreness, fatigue, sleep quality, mood and stress) and PRS.

Methods

Participants

Forty-eight male and female adolescent team sport athletes aged 16-18 years (age 17.3 ± 0.5 years, height 172.8 ± 18.3 cm, body mass 73.6 ± 12.8 kg) participated in this study. Participants were recruited from a local independent school in the United Kingdom (UK), where they were members of the school's sport scholarship programme. The sports cricket (*n*=5), football (*n*=10), hockey (*n*=10), netball (*n*=10) and rugby union (*n*=13) were represented by athletes competing at club/school (*n*=29), professional academy (*n*=6), county/regional (*n*=10) and international (*n*=3) standard in their respective sports. All participants were made aware of the benefits and risks of the study, and written informed consent was provided by all participants and their parents prior to the study. Ethics approval was granted by the University Ethics Committee.

Procedures

Participants completed an online Google Docs (Google Forms, Google, CA, USA) questionnaire before 11am , and prior to their first training session of the day on training days, every morning for a 13-week period. The questionnaire was emailed to participants at 6am every morning and on weekdays they were verbally reminded to complete it if they hadn't done so by 10.30am. The form included a DWB related to fatigue, muscle soreness, sleep quality, stress and mood (McLean, Coutts, Kelly, McGuigan, & Cormack, 2010), with each subscale rated 1-5 and totalled to an overall score out of 25; the PRS (Laurent et al., 2011); self-reported sleep length (in hours) and 24 hour training load recall. For the 24-hour training load recall, participants provided information with regards to the type, intensity and duration of each session from the previous day. Type included technical training, strength and conditioning training, personal gym and matches. All participants were scheduled to complete two technical training sessions, two strength and conditioning training sessions and one match per week as part of their school programmes, but club programmes varied widely by individual. Participants could participate in multiple session types on a single day, but every day where they participated in a match was used to calculate the additive effect of exposure to match play on wellbeing measures. The intensity of each session was rated via the Borg category ratio-10 scale (Foster et al., 2001) choosing the respective descriptor, which was converted to the appropriate rating of perceived exertion (RPE) number and multiplied by the session duration (in minutes) to provide the session-RPE (s-RPE). The sum of all s-RPE's on a single day gave the daily training load. The temporal robustness of the s-RPE method over 24 hours has previously been confirmed (Phibbs et al., 2017; Scantlebury, Till, Sawczuk, Phibbs, & Jones, 2017), and the between-day reliability (typical error as a coefficient of variation) of DWB and PRS has previously been evaluated in this cohort as 11.7% and 8.5% respectively (Sawczuk et al., 2018).

Statistical analyses

For statistical analysis, DWB and PRS scores were converted to scores out of 100.. Data were analysed using SAS University Edition (SAS Institute, Cary, NC). A linear mixed model (via Proc Mixed) was used to evaluate the influence of training load, sleep length and match stress on the dependent variables. The overall DWB score, individual DWB subscales (fatigue, muscle soreness, sleep quality, stress and mood) and PRS score were used as dependent variables. Sport (referring to the athlete's sport), week (referring to the week of the study), and day (referring to the day of the week) were added as fixed factors and provided estimated means for the wellbeing scores for each factor. Training load and sleep duration were mean centred by individual and added as time varying covariates. The additive effect of exposure to match play was calculated by a dummy covariate on any day where the participant reported they had taken part in a match. Athlete*training load*sleep duration was added as an unstructured random effect to allow for variation in the effect of the covariates on the dependent variables between individuals to be calculated. Due to the difficulty in obtaining correlation coefficients from mixed effects models with complicated random effects structures (Roy, 2006), the effect of the covariates was calculated by assessing a two standard deviation (2 SD) difference in the covariate. This evaluates the difference between a typically high and typically low training day/sleep duration, and 'ensures congruence between Cohen's threshold magnitudes for correlations and standardized differences' (Hopkins, Marshall, Batterham, & Hanin, 2009).

Results were analysed for practical significance using magnitude-based inferences (Hopkins et al., 2009). The threshold for a change to be considered practically important (the smallest worthwhile change; SWC) was set as 0.2 x observed between participant SD, based on Cohen's *d* effect size (ES) principle. Thresholds for ES were set as: 0.2 *small;* 0.6 *moderate;* 1.2 *large*, 2.0 *very large.* The ES of random effects were doubled to fit the same ES criteria, as opposed to halving the thresholds (Hopkins, 2015). The probability that the magnitude of change was greater than the SWC 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% *most likely* (Hopkins et al., 2009). In those situations where the likelihood of the magnitude of change was classified as *most likely* greater than the SWC and the ES was greater than 0.6 (i.e. *moderate*), the magnitude-based inference given is compared against the *moderate* effect size rather than the SWC. Effect sizes are reported ES; ± 90% confidence intervals for normally distributed fixed effects and ES; lower 90% confidence interval, upper 90% confidence interval for chi square distributed random effects.

Results

2727 complete data points were analysed for this study at a median response rate of 54/91 completions per person. Overall, 2181 training sessions, 292 matches and 991 rest days were included. The mean daily training load was 250 ± 317 AU and the mean sleep length was 7.7 ± 1.5 hours. A 2 SD difference in training load equated to 556 ± 208 AU, whereas the difference for sleep length was 2.6 ± 1.3 hours.

Figure 1 depicts the influence of training load, exposure to match play and sleep duration on DWB, its individual subscales and PRS. There was *trivial* between-participant variation in the effect of training load on DWB (*d* = 0.18; 0.09, 0.56) and *moderate* between-participant variation in its effect on PRS (*d* = 0.56; 0.31, 1.42). Between-participant variation for the effect of training load on individual subscales ranged from *small* to *moderate* (*d* = 0.22 to 0.80). Sleep duration showed *moderate* variation between participants in its effect on DWB (*d* = 0.66; 0.42, 1.21) and PRS (*d* = 0.64; 0.38, 1.35). Variation in the response to sleep duration ranged from *small* to *large* for the individual DWB subscales (*d* = 0.33 to 1.61).

** INSERT FIGURE 1 HERE **

Discussion

The aim of this study was to assess the influence of training load, exposure to match play and sleep duration on DWB, its individual subscales and PRS. The findings show that training load had a *small* negative effect on muscle soreness and PRS, and that this negative effect was enhanced by a *small* additive effect of exposure to match play on both measures. The influence of training load and match play exposure on all other wellbeing measures was *trivial.* Sleep duration had a *moderate* positive relationship with sleep quality and a *small* positive influence on DWB, fatigue and PRS, but no relationship with muscle soreness, mood or stress.

Training load and match stress

The *small* negative influence of training load and match play exposure on muscle soreness is consistent with Montgomery and Hopkins' (2013) similar findings using the s-RPE method in Australian Rules football players. However, the overall DWB score showed no relationship with training load, conflicting with research in adult Australian Rules football players (Buchheit et al., 2013), but confirming previous findings in youth athletes (Sawczuk et al., 2018). It is possible that these differences can be attributed to a masking effect caused by a lack of responsiveness to training load and match play exposure of other variables within the questionnaire (e.g. mood and stress), as suggested by a recent systematic review (Saw et al., 2016). It has previously been suggested that academic and maturational stressors may hold greater importance than training stressors in this age group (Mountjoy et al., 2008; Sawczuk et al., 2018). Our study cannot add to that hypothesis, but can confirm that the moderate training loads and match stress used in this study have very little direct effect on the mood and stress of youth athletes as measured by this DWB. It is possible that at very high training loads mood and stress measures would be affected, particularly if occurring as a precursor to the overtraining syndrome (Meeusen et al., 2013), but further research is required to confirm this relationship. However, as overtraining only occurs in only 7% of elite youth footballers (Brink, Visscher, Coutts, & Lemmink, 2012), it may be difficult to confirm this hypothesis using a group mean effect as presented here rather than the individual response to training. The lack of relationship with training load does not mean that the mood and stress subscales should immediately be removed from DWB questionnaires though. Mood has previously shown associations with injuries in female collegiate soccer players (Watson, Brickson, Brooks, & Dunn, 2016) and stress can impair the recovery process for up to 96 hours (Stults-Kolehmainen, Bartholomew, & Sinha, 2014), suggesting that there is value in understanding these aspects of an athlete's wellbeing when considering alterations to their training programmes.

In addition to the *small* negative association with muscle soreness, training load and match play exposure showed a *small* negative relationship with PRS, but not with the fatigue subscale of DWB. In line with the super compensation curve dictating that following a training stimulus, an athlete will experience a period of fatigue (Bompa & Haff, 2009), it was expected that both scales would be responsive to training load and exposure to match play. The lack of association between training load and the fatigue subscale is therefore surprising, but the *small* negative relationship between training load and PRS does agree with previous findings in this youth athlete cohort (Sawczuk et al., 2018). It is possible that the difference in the relationships shown is due to the weightings used (fatigue measure as a category scale vs PRS as a category-ratio scale), but it could also be due to the anchoring words employed by the scales. Although the terminology used between the scales is very similar, the PRS, via its terms *"very poorly recovered/extremely tired"* to *"very well recovered/highly energetic"*, possibly places a greater balance on how *recovered* an athlete feels, whereas the fatigue scale, via its terms *"very fresh"* to *"always tired"*, appears to consider how *tired* an athlete is. It is possible that the participants in this study related the term *recovery* to training load and *fatigue* to perceptions of sleep, which may explain the difference in results between the two scales and could also explain why the fatigue scale is much more responsive to sleep duration than the PRS in this population. Alternatively, it is possible that the difference in the two measures is due to the impact training load has on the sleep durations of the individuals. Our study did not consider the interaction between the two measures, but it is likely that those participants who had higher training loads due to evening club training sessions slept less than those who did not due to increased travel time or the need to catch up with academic work. It is therefore possible that their perceptions of fatigue could have been caused by the impact of the previous day's training load on their sleep duration rather than the sleep duration itself.

Sleep duration

Self-reported sleep duration had a *moderate* positive relationship with sleep quality and a *small* positive influence on DWB, fatigue and PRS. These relationships, with four out of the seven variables measured show the importance of sleep as a predictor of changes in sport specific wellbeing questionnaires and highlight this as an under-researched area. The *moderate* positive relationship between sleep duration and sleep quality is unsurprising in its presence as both are subjective measures surrounding sleep, but its size is perhaps smaller than could have been predicted. Indeed, a 2 SD reduction in sleep length (2.6 hours) resulted in only a 0.55 unit change in the sleep quality subscale. A possible reason for this could be the difficulty in defining good sleep quality between individuals, compared to sleep duration, which can be estimated as an arbitrary duration. For example, for some individuals good sleep quality may occur with a long sleep duration, which would provide a good correlation between the two variables, whereas for others it may be based on how many times they wake (consciously or subconsciously) during the night, which may have little relationship with the sleep duration they reported (Krystal & Edinger, 2008). This is supported by the relationship between self-reported sleep duration and actigraphy based total sleep time being very large (r = 0.85), whereas the relationship between subjective sleep quality and sleep efficiency was only small (r = 0.22-0.28) in a recent validation study (Caia et al., 2017). However, the *moderate* relationship between the two variables indicates that they do not provide the same information so, given sleep quality has shown relationships with the other wellbeing measures within DWB (Pilcher, Ginter, & Sadowsky, 1997), there is scope for its consideration as a predictor of changes in DWB, rather than as part of the measure.

The only previous study to consider the influence of sleep duration on sport specific wellbeing questionnaires, such as DWB and PRS, occurred in youth athletes (Sawczuk et al., 2018). The authors found low sleep durations in particular to have a negative influence on DWB, but that PRS had no meaningful relationship with sleep duration. Our study is unable to provide further support for the theory that low sleep durations have a greater impact on DWB than high sleep durations, but does show that a practically meaningful linear relationship can be derived between sleep duration and both DWB and PRS. The relationship between sleep duration and the total score of both measures suggests that it is more important to consider the recovery of youth athletes than any single individual stressor, such as training load, if changes in wellbeing are the main aim of the monitoring process. It remains to be seen whether lack of recovery or excessive training stressors are predictive of adverse outcomes or athletic performance when both are measured together. For example, previous studies have shown spikes in training loads (Putlur et al., 2004) and low sleep durations (Cohen et al., 2009; Prather et al., 2015) to be associated with illness risk, but no study has yet considered these variables together, in which situation one of the training stress imposed or the recovery experienced may be more important than the other.

The *small* relationship between sleep duration and fatigue was expected given previous research (Oginska & Pokorski, 2006). However, the lack of relationship with mood and stress is less congruent with previous research (Oginska & Pokorski, 2006). It has been shown that sleep quality can also affect these variables (Pilcher et al., 1997) so it would be interesting to assess whether quality of sleep is a better predictor of these measures in a sport specific wellbeing questionnaire. The lack of relationship between sleep duration and muscle soreness can probably be attributed to the 24-72 hour time scale of increasing delayed onset muscle soreness (Cheung, Hume, & Maxwelf, 2003). Our study only considered the previous day's sleep duration, which may have limited restorative capabilities over the expected three day cycle, whereas if we had considered the total sleep duration over three days, a relationship may have been found.

Limitations

Although our results add to the literature, particularly through the sample size which is much greater than the previous literature (Buchheit et al., 2013; Thorpe et al., 2017) and the advanced statistical methods used, they are not without their limitations. The first of these is the use of several different sports within the study. Although this increases the ecological validity of the study, it also increases the chance that meaningful effects in one sport (e.g. football) may be lost by the trivial effect of another (e.g. cricket). Unfortunately, participant numbers prevented us from breaking the analysis down into sports to confirm this theory. This is also shown statistically by the *small* to *large* between participant variation in the effect of the predictors on DWB, its individual subscales and PRS. Such variation is indicative of an inconsistent response to predictors (possibly between sports as well as individuals) and ensures that it is difficult to use the mean effect in practice as some athletes will respond considerably better or worse to variations in each predictor. To that end, a move towards considering individualised responses may be more appropriate when datasets allow (Bartlett, O’Connor, Pitchford, Torres-Ronda, & Robertson, 2017; Thornton, Delaney, Duthie, & Dascombe, 2017). Furthermore, the use of self-report measures can be criticised. Although the use of daily wellbeing questionnaires is time and cost efficient in both collection and analysis, they are open to cognitive (e.g. lack of understanding) and conscious (e.g. responding with the answer the athlete believes is correct rather than how they feel) bias (Saw et al., 2015). The use of the 24 hour s-RPE method for total daily training load can also be criticised. In this study, the time and cost effectiveness of the s-RPE method was important given the resources available, however it is not the gold standard of training load measurement. Although the use of s-RPE provides an understanding of how hard an athlete believes they have worked over a day, it does not consider objective markers such as GPS, accelerometer or total resistance volume measures which may provide a more accurate depiction of the total workload produced and have been linked to injury incidence with much more accuracy (Hulin, Gabbett, Lawson, Caputi, & Sampson, 2016; Williams, West, Cross, & Stokes, 2016). The use of a daily s-RPE total also cannot be extrapolated to dose-response changes in fitness unlike other internal load measures, such as heart rate monitoring (Taylor et al., 2018). Self-reported sleep duration has also been criticised in the past as previous studies have shown it can be overestimated by as much as 1-1.5 hours (Caia et al., 2017; Kölling et al., 2016; Lauderdale et al., 2008), suggesting actigraphy may be a more appropriate measure. However, to date there is no research specifically proving that objective measures more accurately influence perceptions of wellbeing than subjective measures. It is therefore possible that perceptions of sleep are more important than actual sleep characteristics when considering the perceptive wellbeing response.

Conclusions

In conclusion, our results show that it is important to consider the recovery of an athlete as well as the training stress they encounter when considering changes in wellbeing measures. In our study, DWB was shown to be responsive to sleep duration, but not training load. However, the individual subscale of muscle soreness was related to training load suggesting that a masking effect may have occurred with the overall score. This does not mean that the subscales not showing a relationship with training load are not valuable because they were, with the exception of the mood and stress subscales, related to the recovery the athlete encountered (measured by sleep duration) and may still be important, either alone or as part of the overall DWB score, for the detection of future adverse events such as injury, illness or overtraining. The PRS on the other hand was related to both the training stressors imposed (training load and additive match play exposure) and the recovery encountered (sleep duration), suggesting that as a single measure to monitor the athletes response to a training programme it may be superior to DWB and its individual subscales. However, like DWB, its relationship with "true" outcome events such as injury, illness and overtraining is yet to be elucidated.

Disclosure of interest

The authors report no conflict of interest.

References

Bartlett, J. D., O'Connor, F., Pitchford, N., Torres-Ronda, L., & Robertson, S. J. (2017). Relationships between internal and external training load in team sport athletes: Evidence for an individualised approach. *International Journal of Sports Physiology and Performance*, *12*(2), 230–234. http://doi.org/10.1123/ijspp.2015-0791

Bompa, T., & Haff, G. (2009). *Periodization. Theory and Methodology of Training* (5th ed.). Champaign, IL: Human Kinetics.

Brink, M. S., Visscher, C., Coutts, A. J., & Lemmink, K. A. (2012). Changes in perceived stress and recovery in overreached young elite soccer players. *Scandinavian Journal of Medicine and Science in Sports*, *22*(2), 285–292. http://doi.org/10.1111/j.1600-0838.2010.01237.x

Buchheit, M., Racinais, S., Bilsborough, J. C., Bourdon, P., Voss, S. C., Hocking, J., … Coutts, A. J. (2013). Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. *Journal of Science and Medicine in Sport*, *16*(6), 550–555. http://doi.org/10.1016/j.jsams.2012.12.003

Caia, J., Thornton, H. R., Kelly, V. G., Scott, T. J., Halson, S. L., Cupples, B., & Driller, M. W. (2017). Does self-perceived sleep reflect sleep estimated via activity monitors in professional rugby league athletes? *Journal of Sports Sciences, epub*. http://doi.org/10.1080/02640414.2017.1398885

Cheung, K., Hume, P. A., & Maxwelf, L. (2003). Delayed onset muscle soreness: Treatment strategies and performance factors. *Sports Medicine*, *33*(2), 145–164.

Cohen, S., Doyle, W. J., Alper, C. M., Janicki-Deverts, D., & Turner, R. B. (2009). Sleep habits and susceptibility to the common cold. *Archives of Internal Medicine*, *169*(1), 62–67. http://doi.org/10.1001/archinternmed.2008.505.Sleep

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., …

Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research*, *15*(1), 109–15.

Fullagar, H. H. K., Skorski, S., Duffield, R., Hammes, D., Coutts, A. J., & Meyer, T. (2015). Sleep and athletic performance: The effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Medicine*, *45*(2), 161–186. http://doi.org/10.1007/s40279-014-0260-0

Gallo, T. F., Cormack, S. J., Gabbett, T. J., & Lorenzen, C. H. (2017). Self-reported wellness profiles of professional Australian football players during the competition phase of the season. *Journal of Strength and Conditioning Research, 31*(2), 495–502.

Halson, S. L. (2014a). Monitoring training load to understand fatigue in athletes. *Sports Medicine*, *44*(S2), S139-147. http://doi.org/10.1007/s40279-014-0253-z

Halson, S. L. (2014b). Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Medicine*, *44*(S1), 13–23. http://doi.org/10.1007/s40279-014-0147-0

Hopkins, W. G. (2015). Individual responses made easy. *Journal of Applied Physiology, 118*(12), 1444–1446. http://doi.org/10.1152/japplphysiol.00098.2015

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12. http://doi.org/10.1249/MSS.0b013e31818cb278

Hulin, B. T., Gabbett, T. J., Blanch, P., Chapman, P., Bailey, D., & Orchard, J. W. (2014). Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *British Journal of Sports Medicine*, *48*(8), 708–712. http://doi.org/10.1136/bjsports-2013-092524

Hulin, B. T., Gabbett, T. J., Lawson, D. W., Caputi, P., & Sampson, J. A. (2016). The acute:chronic workload ratio predicts injury: High chronic workload may decrease injury risk in elite rugby league players. *British Journal of Sports Medicine*, *50*(4), 231–236. http://doi.org/10.1136/bjsports-2015-094817

Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scandinavian Journal of Medicine & Science in Sports*, *20*(S2), 95–102. http://doi.org/10.1111/j.1600-0838.2010.01192.x

Kölling, S., Endler, S., Ferrauti, A., Meyer, T., & Kellmann, M. (2016). Comparing subjective with objective sleep parameters via multisensory actigraphy in German physical education students. *Behavioral Sleep Medicine*, *14*(4), 389–405. http://doi.org/10.1080/15402002.2015.1017096

Krystal, A. D., & Edinger, J. D. (2008). Measuring sleep quality. *Journal of Sleep Medicine*, *9*(S1), S10–S17.

Lauderdale, D. S., Knutson, K. L., Yan, L. L., Liu, K., & Rathouz, P. J. (2008). Sleep duration: How well do self-reports reflect objective measures? The CARDIA Sleep Study. *Epidemiology*, *19*(6), 838–845. http://doi.org/10.1097/EDE.0b013e318187a7b0.Sleep

Laurent, C. M., Green, J. M., Bishop, P. A., Sjokvist, J., Schumacher, R. E., Richardson, M. T., & Curtner-Smith, M. (2011). A practical approach to monitoring recovery: Development of a perceived recovery status scale. *Journal of Strength and Conditioning Research*, *25*(3), 620–628.

Mah, C. D., Mah, K. E., Kezirian, E. J., & Dement, W. C. (2011). The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep*, *34*(7), 943–950. http://doi.org/10.5665/sleep.1132

McLean, B. D., Coutts, A. J., Kelly, V., McGuigan, M. R., & Cormack, S. J. (2010). Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance*, *5*(3), 367–383.

Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., … Urhausen, A. (2013). 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. *Medicine & Science in Sports & Exercise*, *45*(1), 186–205. http://doi.org/10.1249/MSS.0b013e318279a10a

Montgomery, P. G., & Hopkins, W. G. (2013). The effects of game and training loads on perceptual responses of muscle soreness in Australian Football. *International Journal of Sports Physiology and Performance*, *8*(3), 312–318. http://doi.org/2012-0181 [pii]

Mountjoy, M., Armstrong, N., Bizzini, L., Blimkie, C., Evans, J., Gerrard, D., … Van Mechelen, W. (2008). IOC consensus statement: “Training the elite child athlete.” *British Journal of Sports Medicine*, *42*(3), 163–164. http://doi.org/10.1136/bjsm.2007.044016

Noon, M. R., James, R. S., Clarke, N. D., Akubat, I., & Thake, C. D. (2015). Perceptions of well-being and physical performance in English elite youth footballers across a season. *Journal of Sports Sciences*, *33*(20), 2106–2115. http://doi.org/10.1080/02640414.2015.1081393

Oginska, H., & Pokorski, J. (2006). Fatigue and mood correlates of sleep length in three age-social groups: School children, students, and employees. *Chronobiology Iternational*, *23*(6), 1317–1328. http://doi.org/10.1080/07420520601089349

Phibbs, P., Roe, G., Jones, B., Read, D., Darrall-Jones, J., Weakley, J., & Till, K. (2017). Validity of daily and weekly self-reported training load measures in adolescent athletes. *Journal of Strength and Conditioning Research*, *31*(4), 1121–1126. http://doi.org/10.1519/JSC.0000000000001708

Pilcher, J. J., Ginter, D. R. ., & Sadowsky, B. (1997). Sleep quality versus sleep quantity: Relationships between sleep and measures of health, well-being and sleepiness in college students. *Journal of Psychosomatic Research*, *42*(6), 583–596. http://doi.org/10.1016/S0022-3999(97)00004-4

Prather, A. A., Janicki-Deverts, D., Hall, M. H., & Cohen, S. (2015). Behaviorally assessed sleep and susceptibility to the common cold. *Sleep*, *38*(9), 1353–1359.

Putlur, P., Foster, C., Miskowski, J. A., Kane, M. K., Burton, S. E., Scheett, T. P., & McGuigan, M. R. (2004). Alteration of immune function in women collegiate soccer players and college students. *Journal of Sports Science and Medicine*, *3*(4), 234–243.

Rowbottom, D. G. (2000). Periodization of training. In W. E. Garrett & D. T. Kirkendall (Eds.), *Exercise and Sport Science* (pp. 499–514). Philadelphia: Lippincott, Williams and Wilkins.

Roy, A. (2006). Estimating correlation coefficient between two variables with repeated observations using mixed effects model. *Biometrical Journal*, *48*(2), 286–301. http://doi.org/10.1002/bimj.200510192

Saw, A. E., Main, L. C., & Gastin, P. B. (2015). Monitoring athletes through self-report: Factors influencing implementation. *Journal of Sports Science and Medicine*, *14*(1), 137–146. http://doi.org/10.1519/JSC.0000000000000499

Saw, A. E., Main, L. C., & Gastin, P. B. (2016). Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. *British Journal of Sports Medicine*, *50*(5), 281–291. http://doi.org/10.1136/bjsports-2015-094758

Sawczuk, T., Jones, B., Scantlebury, S., & Till, K. (2018). Relationships between training load, sleep duration, and daily wellbeing and recovery measures in youth athletes. *Pediatric Exercise Science*, *epub ahead of print*.

Scantlebury, S., Till, K., Sawczuk, T., Phibbs, P., & Jones, B. (2017). The validity of retrospective session-rating of perceived exertion to quantify training load in youth athletes. *Journal of Strength and Conditioning Research, epub ahead of print*. http://doi.org/10.1519/JSC.0000000000002099

Siesmaa, E. J., Blitvich, J. D., & Finch, C. F. (2011). A systematic review of the factors which are most influential in children's decisions to drop out of organised sport. In A. D. Farelli (Ed.), *Sport Participation: Health Benefits, Injuries and Psychological Effects* (pp. 1–45). Hauppauge, NY: Nova Science.

Stults-Kolehmainen, M. A., Bartholomew, J. B., & Sinha, R. (2014). Chronic psychological stress impairs recovery of muscular function and somatic sensations over a 96-hour period. *Journal of Strength and Conditioning Research*, *28*(7), 2007–2017. http://doi.org/10.1519/JSC.0000000000000335

Taylor, R., Sanders, D., Myers, T., Abt, G., Taylor, C. A., & Akubat, I. (2018). The dose-response relationship between training load and aerobic fitness in academy rugby union players. *International Journal of Sports Physiology and Performance, epub ahead of print*. http://doi.org/10.1123/ijspp.2017-0121

Thornton, H. R., Delaney, J. A., Duthie, G. M., & Dascombe, B. J. (2017). Importance of various training load measures on injury incidence of professional rugby league athletes. *International Journal of Sports Physiology and Performance, epub ahead of print*. http://doi.org/10.1123/ijspp.2016-0326

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2015). Monitoring fatigue during the in-season competitive phase in elite soccer players. *International Journal of Sports Physiology and Performance*, *10*(8), 958–964.

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2017). The influence of changes in acute training load on daily sensitivity of morning measured fatigue variables in elite soccer players. *International Journal of Sports*

Physiology and Performance, *12*(S2), S2107–S2113.

Tuomilehto, H., Vuorinen, V. P., Penttilä, E., Kivimäki, M., Vuorenmaa, M., Venojärvi, M., … Pihlajamäki, J. (2017). Sleep of professional athletes: Underexploited potential to improve health and performance. *Journal of Sports Sciences*, *35*(7), 704–710. http://doi.org/10.1080/02640414.2016.1184300

Watson, A., Brickson, S., Brooks, A., & Dunn, W. (2016). Subjective well-being and training load predict in-season injury and illness risk in female youth soccer players. *British Journal of Sports Medicine*, *epub ahead of print.*

Williams, S., West, S., Cross, M. J., & Stokes, K. A. (2016). A better way to determine the acute:chronic workload ratio? *British Journal of Sports Medicine*.

Figure 1: The influence of training load, exposure to match play and sleep duration on the overall DWB score, its individual subscales and PRS. Data are presented as effect size with 90% confidence intervals, shaded area denotes smallest worthwhile change.