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

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

4

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

6

7 Thomas Sawczuk^{1,2}, Ben Jones^{1,2,3,4,5}, Sean Scantlebury^{1,2}, Kevin Till^{1,3,5}

8

9 ¹ Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds,

10 United Kingdom

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

12 ³ Yorkshire Carnegie Rugby Club, Headingley Carnegie Stadium, Leeds, United Kingdom

13 ⁴ The Rugby Football League, Red Hall, Leeds, United Kingdom

14 ⁵ Leeds Rhinos Rugby Club, Headingley Carnegie Stadium, Leeds, United Kingdom

15

16 Corresponding Author:

17 Thomas Sawczuk

18 Room G03, Macaulay Hall;

19 Institute for Sport, Physical Activity and Leisure, Centre for Sports Performance;

20 Leeds Beckett University, Headingley Campus;

21 West Yorkshire;

22 LS6 3QS

23 Email: t.sawczuk@leedsbeckett.ac.uk

24 Phone: (0044) 7530 945555

25 Abstract

26 This study assessed the influence of training load, exposure to match play and sleep
27 duration on two daily wellbeing measures in youth athletes. Forty-eight youth athletes (age
28 17.3 ± 0.5 years) completed a daily wellbeing questionnaire (DWB), the Perceived
29 Recovery Status scale (PRS), and provided details on the previous day's training loads
30 (TL) and self-reported sleep duration (sleep) every day for 13 weeks ($n = 2727$). A linear
31 mixed model assessed the effect of TL, exposure to match play and sleep on DWB and
32 PRS. An increase in TL had a *most likely small* effect on muscle soreness ($d=-0.43\pm0.10$)
33 and PRS ($d=-0.37\pm0.09$). Match play had a *likely small* additive effect on muscle soreness
34 ($d=-0.26\pm0.09$) and PRS ($d=-0.25\pm0.08$). An increase in sleep had a *most likely moderate*
35 effect on sleep quality ($d=0.80\pm0.14$); a *most likely small* effect on DWB ($d=0.45\pm0.09$)
36 and fatigue ($d=0.42\pm0.11$); and a *likely small* effect on PRS ($d=0.25\pm0.09$). All other
37 effects were *trivial* or did not reach the pre-determined threshold for practical significance.
38 The influence of sleep on multiple DWB subscales and the PRS suggests that practitioners
39 should consider the recovery of an athlete alongside the training stress imposed when
40 considering deviations in wellbeing measures.

41

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44 **Introduction**

45 It is essential that an optimal balance between stress and recovery is reached when
46 constructing athletic development programmes (Rowbottom, 2000). The stress-recovery
47 balance dictates that when a body is subjected to a stressor (e.g. training load, examination
48 stress or social pressures), an appropriate amount of recovery time (e.g. sleep) is required
49 to maintain equilibrium (Kellmann, 2010). In sport, failure to maintain the stress-recovery
50 balance can result in de-training, injury, illness or overtraining (Hulin et al., 2014;
51 Meeusen et al., 2013; Putlur et al., 2004). Consequently, it has become commonplace to
52 monitor an athlete's stress-recovery balance using subjective daily wellbeing
53 questionnaires (DWB; Saw, Main, & Gastin, 2015). These questionnaires, as self-report
54 measures, are now widespread in professional adult sport due to their inexpensiveness,
55 time efficiency and ease of analysis (Saw et al., 2015; Saw, Main, & Gastin, 2016), but are
56 also becoming increasingly prominent at youth level (Noon, James, Clarke, Akubat, &
57 Thake, 2015; Sawczuk, Jones, Scantlebury, & Till, 2018). However, the stress-recovery
58 balance at youth level may vary in response to training stressors as athletes attempt to cope
59 with educational (e.g. academic examinations), maturational (e.g. hormonal changes) and
60 social (e.g. pressure to succeed, relationships and peer pressure) demands alongside their
61 sporting endeavours (Mountjoy et al., 2008; Siesmaa, Blitvich, & Finch, 2011). In order
62 for wellbeing questionnaires to be fit for purpose, it is important that they are responsive to
63 the stress and recovery experienced by the athlete. In sport, the primary stressor imposed
64 upon an athlete by the coaching staff, aimed at enhancing their athletic development, is the
65 training stimulus, whereas the primary mechanism of recovery is sleep (Halsen, 2014a,
66 2014b). However, whilst there is a growing body of literature considering the influence of
67 training load on DWB (Buchheit et al., 2013; Thorpe et al., 2017), studies considering their
68 relationship with sleep are scarce (Sawczuk et al., 2018).

69
70 The influence of training load on overall DWB scores appears surprisingly contentious
71 given their widespread use in sport (Saw et al., 2015). Buchheit and colleagues (2013)
72 found a DWB and all its individual subscales (i.e. measures of fatigue, muscle soreness,
73 sleep quality, stress and mood) to be related to training load in Australian Rules football
74 players during the pre-season phase. However, other studies in Australian Rules football
75 players (Gallo, Cormack, Gabbett, & Lorenzen, 2017) and youth athletes (Sawczuk et al.,
76 2018) have argued that the overall DWB score is not influenced by the previous day's
77 workload. It is possible that the difference between these studies is due to the training loads
78 present. Buchheit and colleagues (2013) reported a weekly training load of over 10,000
79 AU in their study, whereas both studies reporting no change had weekly training loads of
80 around 1,750 AU (Gallo et al., 2017; Sawczuk et al., 2018). Furthermore, only Buchheit
81 and colleagues (2013) provided a DWB subscale analysis which showed all subscales to
82 have a *small* association with training load. Given that very high training loads are
83 believed to affect mood and stress prior to the onset of the overtraining syndrome
84 (Meeusen et al., 2013) and neither Gallo and colleagues (2017) nor Sawczuk and
85 colleagues' (2017) studies included very high training loads, it is possible that a masking
86 effect between subscales occurred within the studies showing no relationship between
87 DWB and training load. Therefore, fatigue, muscle soreness and sleep quality may have
88 been affected by training load but a lack of association with other subscales could have
89 blunted the overall response. Previous studies have shown that individual subscales such as
90 fatigue (Thorpe et al., 2015, 2017), muscle soreness (Montgomery & Hopkins, 2013), and
91 the PRS (Sawczuk et al., 2018) may be affected by training load and exposure to match
92 play at training loads between 1,750 and 2,000 AU, supporting this hypothesis. However,
93 none of these studies analysed the effect of these training loads on mood or stress

94 subscales. A study considering the effect of moderate weekly training loads (circa 2,000
95 AU per week), including exposure to match play, on the overall DWB score and all
96 individual subscales, and a comparison with the PRS, a standalone scale shown to be
97 sensitive to training loads (Sawczuk et al., 2018), is therefore merited.

98

99 In order to recover from the training and match stimuli encountered by athletes, it is
100 important that sleep is optimised (Halson, 2014b; Tuomilehto et al., 2017). Previous
101 research has indicated that sleep can affect sporting performance (Fullagar et al., 2015;
102 Mah, Mah, Kezirian, & Dement, 2011), risk of illness (Cohen, Doyle, Alper, Janicki-
103 Deverts, & Turner, 2009; Prather, Janicki-Deverts, Hall, & Cohen, 2015) and wellbeing
104 measures (Oginska & Pokorski, 2006). Despite this evidence showing the importance of
105 sleep, previous studies have avoided the use of self-reported sleep duration as a predictor
106 of changes in wellbeing measures due to its perceived lack of validity when compared to
107 actigraphy measures (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). However, it has
108 recently become apparent that in athletic populations self-reported sleep duration is a valid
109 measure when compared to actigraphy (Caia et al., 2017; Kölling, Endler, Ferrauti, Meyer,
110 & Kellmann, 2016), although it maintains its systematic bias of overestimating sleep
111 duration by around 1 hour. These new findings, alongside suggestions that perceptions of
112 sleep quality are not always congruent with objective measures (Krystal & Edinger, 2008),
113 provide rationale for the use of self-reported sleep duration as a predictor of changes in
114 wellbeing. To date, the only study to have considered the influence of sleep duration on a
115 sport specific wellbeing measure found DWB to be related to short, but not extended, sleep
116 durations and found no relationship with the PRS (Sawczuk et al., 2018). However, the
117 study only took place on four weekdays, which may not be representative of a youth
118 athlete population as participants would likely have had to be at school by 8.30am on those

119 weekdays, whereas their sleep durations may not be similarly restricted at weekends.
120 Furthermore, the inclusion of a sleep quality measure within the overall DWB score could
121 have skewed the true relationship, but an individual subscale analysis was not provided in
122 the study. Therefore, there is scope for a study considering all seven days, in which the
123 influence of self-reported sleep length on DWB, its individual subscales and the PRS is
124 considered, alongside training loads and match stress. Consequently, the aim of this study
125 was to assess the influence of training load, exposure to match play and self-reported sleep
126 duration on a DWB, its individual subscales (i.e. muscle soreness, fatigue, sleep quality,
127 mood and stress) and PRS.

128

129 **Methods**

130 *Participants*

131 Forty-eight male and female adolescent team sport athletes aged 16-18 years (age $17.3 \pm$
132 0.5 years, height 172.8 ± 18.3 cm, body mass 73.6 ± 12.8 kg) participated in this study.
133 Participants were recruited from a local independent school in the United Kingdom (UK),
134 where they were members of the school's sport scholarship programme. The sports cricket
135 ($n=5$), football ($n=10$), hockey ($n=10$), netball ($n=10$) and rugby union ($n=13$) were
136 represented by athletes competing at club/school ($n=29$), professional academy ($n=6$),
137 county/regional ($n=10$) and international ($n=3$) standard in their respective sports. All
138 participants were made aware of the benefits and risks of the study, and written informed
139 consent was provided by all participants and their parents prior to the study. Ethics
140 approval was granted by the University Ethics Committee.

141

142 *Procedures*

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

168

169 *Statistical analyses*

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

189

190 Results were analysed for practical significance using magnitude-based inferences
191 (Hopkins et al., 2009). The threshold for a change to be considered practically important
192 (the smallest worthwhile change; SWC) was set as 0.2 x observed between participant SD,

193 based on Cohen's *d* effect size (ES) principle. Thresholds for ES were set as: 0.2 *small*; 0.6
194 *moderate*; 1.2 *large*, 2.0 *very large*. The ES of random effects were doubled to fit the same
195 ES criteria, as opposed to halving the thresholds (Hopkins, 2015). The probability that the
196 magnitude of change was greater than the SWC was rated as: <0.5% *almost certainly not*;
197 0.5-5% *very unlikely*; 5-25% *unlikely*; 25-75% *possibly*; 75-95% *likely*; 95-99.5% *very*
198 *likely*; >99.5% *most likely* (Hopkins et al., 2009). In those situations where the likelihood
199 of the magnitude of change was classified as *most likely* greater than the SWC and the ES
200 was greater than 0.6 (i.e. *moderate*), the magnitude-based inference given is compared
201 against the *moderate* effect size rather than the SWC. Effect sizes are reported ES; \pm 90%
202 confidence intervals for normally distributed fixed effects and ES; lower 90% confidence
203 interval, upper 90% confidence interval for chi square distributed random effects.

204

205 **Results**

206 2727 complete data points were analysed for this study at a median response rate of 54/91
207 completions per person. Overall, 2181 training sessions, 292 matches and 991 rest days
208 were included. The mean daily training load was 250 ± 317 AU and the mean sleep length
209 was 7.7 ± 1.5 hours. A 2 SD difference in training load equated to 556 ± 208 AU, whereas
210 the difference for sleep length was 2.6 ± 1.3 hours.

211

212 Figure 1 depicts the influence of training load, exposure to match play and sleep duration
213 on DWB, its individual subscales and PRS. There was *trivial* between-participant variation
214 in the effect of training load on DWB ($d = 0.18$; 0.09, 0.56) and *moderate* between-
215 participant variation in its effect on PRS ($d = 0.56$; 0.31, 1.42). Between-participant
216 variation for the effect of training load on individual subscales ranged from *small* to
217 *moderate* ($d = 0.22$ to 0.80). Sleep duration showed *moderate* variation between

218 participants in its effect on DWB ($d = 0.66$; 0.42, 1.21) and PRS ($d = 0.64$; 0.38, 1.35).
219 Variation in the response to sleep duration ranged from *small* to *large* for the individual
220 DWB subscales ($d = 0.33$ to 1.61).

221

222 ** INSERT FIGURE 1 HERE **

223

224 **Discussion**

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

233

234 *Training load and match stress*

235 The *small* negative influence of training load and match play exposure on muscle soreness
236 is consistent with Montgomery and Hopkins' (2013) similar findings using the s-RPE
237 method in Australian Rules football players. However, the overall DWB score showed no
238 relationship with training load, conflicting with research in adult Australian Rules football
239 players (Buchheit et al., 2013), but confirming previous findings in youth athletes
240 (Sawczuk et al., 2018). It is possible that these differences can be attributed to a masking
241 effect caused by a lack of responsiveness to training load and match play exposure of other
242 variables within the questionnaire (e.g. mood and stress), as suggested by a recent

243 systematic review (Saw et al., 2016). It has previously been suggested that academic and
244 maturational stressors may hold greater importance than training stressors in this age group
245 (Mountjoy et al., 2008; Sawczuk et al., 2018). Our study cannot add to that hypothesis, but
246 can confirm that the moderate training loads and match stress used in this study have very
247 little direct effect on the mood and stress of youth athletes as measured by this DWB. It is
248 possible that at very high training loads mood and stress measures would be affected,
249 particularly if occurring as a precursor to the overtraining syndrome (Meeusen et al.,
250 2013), but further research is required to confirm this relationship. However,
251 as overtraining only occurs in only 7% of elite youth footballers (Brink, Visscher, Coutts,
252 & Lemmink, 2012), it may be difficult to confirm this hypothesis using a group mean
253 effect as presented here rather than the individual response to training. The lack of
254 relationship with training load does not mean that the mood and stress subscales should
255 immediately be removed from DWB questionnaires though. Mood has previously shown
256 associations with injuries in female collegiate soccer players (Watson, Brickson, Brooks, &
257 Dunn, 2016) and stress can impair the recovery process for up to 96 hours (Stults-
258 Kolehmainen, Bartholomew, & Sinha, 2014), suggesting that there is value in
259 understanding these aspects of an athlete's wellbeing when considering alterations to their
260 training programmes.

261

262 In addition to the *small* negative association with muscle soreness, training load and match
263 play exposure showed a *small* negative relationship with PRS, but not with the fatigue
264 subscale of DWB. In line with the super compensation curve dictating that following a
265 training stimulus, an athlete will experience a period of fatigue (Bompa & Haff, 2009), it
266 was expected that both scales would be responsive to training load and exposure to match
267 play. The lack of association between training load and the fatigue subscale is therefore

268 surprising, but the *small* negative relationship between training load and PRS does agree
269 with previous findings in this youth athlete cohort (Sawczuk et al., 2018). It is possible that
270 the difference in the relationships shown is due to the weightings used (fatigue measure as
271 a category scale vs PRS as a category-ratio scale), but it could also be due to the anchoring
272 words employed by the scales. Although the terminology used between the scales is very
273 similar, the PRS, via its terms "*very poorly recovered/extremely tired*" to "*very well*
274 *recovered/highly energetic*", possibly places a greater balance on how *recovered* an athlete
275 feels, whereas the fatigue scale, via its terms "*very fresh*" to "*always tired*", appears to
276 consider how *tired* an athlete is. It is possible that the participants in this study related the
277 term *recovery* to training load and *fatigue* to perceptions of sleep, which may explain the
278 difference in results between the two scales and could also explain why the fatigue scale is
279 much more responsive to sleep duration than the PRS in this population. Alternatively, it is
280 possible that the difference in the two measures is due to the impact training load has on
281 the sleep durations of the individuals. Our study did not consider the interaction between
282 the two measures, but it is likely that those participants who had higher training loads due
283 to evening club training sessions slept less than those who did not due to increased travel
284 time or the need to catch up with academic work. It is therefore possible that their
285 perceptions of fatigue could have been caused by the impact of the previous day's training
286 load on their sleep duration rather than the sleep duration itself.

287

288 *Sleep duration*

289 Self-reported sleep duration had a *moderate* positive relationship with sleep quality and a
290 *small* positive influence on DWB, fatigue and PRS. These relationships, with four out of
291 the seven variables measured show the importance of sleep as a predictor of changes in
292 sport specific wellbeing questionnaires and highlight this as an under-researched area. The

293 *moderate* positive relationship between sleep duration and sleep quality is unsurprising in
294 its presence as both are subjective measures surrounding sleep, but its size is perhaps
295 smaller than could have been predicted. Indeed, a 2 SD reduction in sleep length (2.6
296 hours) resulted in only a 0.55 unit change in the sleep quality subscale. A possible reason
297 for this could be the difficulty in defining good sleep quality between individuals,
298 compared to sleep duration, which can be estimated as an arbitrary duration. For example,
299 for some individuals good sleep quality may occur with a long sleep duration, which would
300 provide a good correlation between the two variables, whereas for others it may be based
301 on how many times they wake (consciously or subconsciously) during the night, which
302 may have little relationship with the sleep duration they reported (Krystal & Edinger,
303 2008). This is supported by the relationship between self-reported sleep duration and
304 actigraphy based total sleep time being very large ($r = 0.85$), whereas the relationship
305 between subjective sleep quality and sleep efficiency was only small ($r = 0.22-0.28$) in a
306 recent validation study (Caia et al., 2017). However, the *moderate* relationship between the
307 two variables indicates that they do not provide the same information so, given sleep
308 quality has shown relationships with the other wellbeing measures within DWB (Pilcher,
309 Ginter, & Sadowsky, 1997), there is scope for its consideration as a predictor of changes in
310 DWB, rather than as part of the measure.

311

312 The only previous study to consider the influence of sleep duration on sport specific
313 wellbeing questionnaires, such as DWB and PRS, occurred in youth athletes (Sawczuk et
314 al., 2018). The authors found low sleep durations in particular to have a negative influence
315 on DWB, but that PRS had no meaningful relationship with sleep duration. Our study is
316 unable to provide further support for the theory that low sleep durations have a greater
317 impact on DWB than high sleep durations, but does show that a practically meaningful

318 linear relationship can be derived between sleep duration and both DWB and PRS. The
319 relationship between sleep duration and the total score of both measures suggests that it is
320 more important to consider the recovery of youth athletes than any single individual
321 stressor, such as training load, if changes in wellbeing are the main aim of the monitoring
322 process. It remains to be seen whether lack of recovery or excessive training stressors are
323 predictive of adverse outcomes or athletic performance when both are measured together.
324 For example, previous studies have shown spikes in training loads (Putlur et al., 2004) and
325 low sleep durations (Cohen et al., 2009; Prather et al., 2015) to be associated with illness
326 risk, but no study has yet considered these variables together, in which situation one of the
327 training stress imposed or the recovery experienced may be more important than the other.
328

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

340

341 *Limitations*

342 Although our results add to the literature, particularly through the sample size which is
343 much greater than the previous literature (Buchheit et al., 2013; Thorpe et al., 2017) and
344 the advanced statistical methods used, they are not without their limitations. The first of
345 these is the use of several different sports within the study. Although this increases the
346 ecological validity of the study, it also increases the chance that meaningful effects in one
347 sport (e.g. football) may be lost by the trivial effect of another (e.g. cricket). Unfortunately,
348 participant numbers prevented us from breaking the analysis down into sports to confirm
349 this theory. This is also shown statistically by the *small to large* between participant
350 variation in the effect of the predictors on DWB, its individual subscales and PRS. Such
351 variation is indicative of an inconsistent response to predictors (possibly between sports as
352 well as individuals) and ensures that it is difficult to use the mean effect in practice as
353 some athletes will respond considerably better or worse to variations in each predictor. To
354 that end, a move towards considering individualised responses may be more appropriate
355 when datasets allow (Bartlett, O'Connor, Pitchford, Torres-Ronda, & Robertson, 2017;
356 Thornton, Delaney, Duthie, & Dascombe, 2017). Furthermore, the use of self-report
357 measures can be criticised. Although the use of daily wellbeing questionnaires is time and
358 cost efficient in both collection and analysis, they are open to cognitive (e.g. lack of
359 understanding) and conscious (e.g. responding with the answer the athlete believes is
360 correct rather than how they feel) bias (Saw et al., 2015). The use of the 24 hour s-RPE
361 method for total daily training load can also be criticised. In this study, the time and cost
362 effectiveness of the s-RPE method was important given the resources available, however it
363 is not the gold standard of training load measurement. Although the use of s-RPE provides
364 an understanding of how hard an athlete believes they have worked over a day, it does not
365 consider objective markers such as GPS, accelerometer or total resistance volume
366 measures which may provide a more accurate depiction of the total workload produced and

367 have been linked to injury incidence with much more accuracy (Hulin, Gabbett, Lawson,
368 Caputi, & Sampson, 2016; Williams, West, Cross, & Stokes, 2016). The use of a daily s-
369 RPE total also cannot be extrapolated to dose-response changes in fitness unlike other
370 internal load measures, such as heart rate monitoring (Taylor et al., 2018). Self-reported
371 sleep duration has also been criticised in the past as previous studies have shown it can be
372 overestimated by as much as 1-1.5 hours (Caia et al., 2017; Kölling et al., 2016;
373 Lauderdale et al., 2008), suggesting actigraphy may be a more appropriate measure.
374 However, to date there is no research specifically proving that objective measures more
375 accurately influence perceptions of wellbeing than subjective measures. It is therefore
376 possible that perceptions of sleep are more important than actual sleep characteristics when
377 considering the perceptive wellbeing response.

378

379 **Conclusions**

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

392 athletes response to a training programme it may be superior to DWB and its individual
393 subscales. However, like DWB, its relationship with "true" outcome events such as injury,
394 illness and overtraining is yet to be elucidated.

395

396 **Disclosure of interest**

397 The authors report no conflict of interest.

398 **References**

- 399 Bartlett, J. D., O'Connor, F., Pitchford, N., Torres-Ronda, L., & Robertson, S. J. (2017).
 400 Relationships between internal and external training load in team sport athletes:
 401 Evidence for an individualised approach. *International Journal of Sports Physiology
 402 and Performance*, *12*(2), 230–234. <http://doi.org/10.1123/ijsp.2015-0791>
- 403 Bompa, T., & Haff, G. (2009). *Periodization. Theory and Methodology of Training* (5th
 404 ed.). Champaign, IL: Human Kinetics.
- 405 Brink, M. S., Visscher, C., Coutts, A. J., & Lemmink, K. A. (2012). Changes in perceived
 406 stress and recovery in overreached young elite soccer players. *Scandinavian Journal
 407 of Medicine and Science in Sports*, *22*(2), 285–292. [http://doi.org/10.1111/j.1600-
 408 0838.2010.01237.x](http://doi.org/10.1111/j.1600-0838.2010.01237.x)
- 409 Buchheit, M., Racinais, S., Bilsborough, J. C., Bourdon, P., Voss, S. C., Hocking, J., ...
 410 Coutts, A. J. (2013). Monitoring fitness, fatigue and running performance during a
 411 pre-season training camp in elite football players. *Journal of Science and Medicine in
 412 Sport*, *16*(6), 550–555. <http://doi.org/10.1016/j.jsams.2012.12.003>
- 413 Caia, J., Thornton, H. R., Kelly, V. G., Scott, T. J., Halson, S. L., Cupples, B., & Driller,
 414 M. W. (2017). Does self-perceived sleep reflect sleep estimated via activity monitors
 415 in professional rugby league athletes? *Journal of Sports Sciences*, *epub*.
 416 <http://doi.org/10.1080/02640414.2017.1398885>
- 417 Cheung, K., Hume, P. A., & Maxwell, L. (2003). Delayed onset muscle soreness:
 418 Treatment strategies and performance factors. *Sports Medicine*, *33*(2), 145–164.
- 419 Cohen, S., Doyle, W. J., Alper, C. M., Janicki-Deverts, D., & Turner, R. B. (2009). Sleep
 420 habits and susceptibility to the common cold. *Archives of Internal Medicine*, *169*(1),
 421 62–67. <http://doi.org/10.1001/archinternmed.2008.505>.Sleep
- 422 Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., ...

- 423 Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of*
424 *Strength and Conditioning Research*, *15*(1), 109–15.
- 425 Fullagar, H. H. K., Skorski, S., Duffield, R., Hammes, D., Coutts, A. J., & Meyer, T.
426 (2015). Sleep and athletic performance: The effects of sleep loss on exercise
427 performance, and physiological and cognitive responses to exercise. *Sports Medicine*,
428 *45*(2), 161–186. <http://doi.org/10.1007/s40279-014-0260-0>
- 429 Gallo, T. F., Cormack, S. J., Gabbett, T. J., & Lorenzen, C. H. (2017). Self-reported
430 wellness profiles of professional Australian football players during the competition
431 phase of the season. *Journal of Strength and Conditioning Research*, *31*(2), 495–502.
- 432 Halson, S. L. (2014a). Monitoring training load to understand fatigue in athletes. *Sports*
433 *Medicine*, *44*(S2), S139-147. <http://doi.org/10.1007/s40279-014-0253-z>
- 434 Halson, S. L. (2014b). Sleep in elite athletes and nutritional interventions to enhance sleep.
435 *Sports Medicine*, *44*(S1), 13–23. <http://doi.org/10.1007/s40279-014-0147-0>
- 436 Hopkins, W. G. (2015). Individual responses made easy. *Journal of Applied Physiology*,
437 *118*(12), 1444–1446. <http://doi.org/10.1152/jappphysiol.00098.2015>
- 438 Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive
439 statistics for studies in sports medicine and exercise science. *Medicine and Science in*
440 *Sports and Exercise*, *41*(1), 3–12. <http://doi.org/10.1249/MSS.0b013e31818cb278>
- 441 Hulin, B. T., Gabbett, T. J., Blanch, P., Chapman, P., Bailey, D., & Orchard, J. W. (2014).
442 Spikes in acute workload are associated with increased injury risk in elite cricket fast
443 bowlers. *British Journal of Sports Medicine*, *48*(8), 708–712.
444 <http://doi.org/10.1136/bjsports-2013-092524>
- 445 Hulin, B. T., Gabbett, T. J., Lawson, D. W., Caputi, P., & Sampson, J. A. (2016). The
446 acute:chronic workload ratio predicts injury: High chronic workload may decrease
447 injury risk in elite rugby league players. *British Journal of Sports Medicine*, *50*(4),

- 448 231–236. <http://doi.org/10.1136/bjsports-2015-094817>
- 449 Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and
450 stress/recovery monitoring. *Scandinavian Journal of Medicine & Science in Sports*,
451 20(S2), 95–102. <http://doi.org/10.1111/j.1600-0838.2010.01192.x>
- 452 Kölling, S., Endler, S., Ferrauti, A., Meyer, T., & Kellmann, M. (2016). Comparing
453 subjective with objective sleep parameters via multisensory actigraphy in German
454 physical education students. *Behavioral Sleep Medicine*, 14(4), 389–405.
455 <http://doi.org/10.1080/15402002.2015.1017096>
- 456 Krystal, A. D., & Edinger, J. D. (2008). Measuring sleep quality. *Journal of Sleep*
457 *Medicine*, 9(S1), S10–S17.
- 458 Lauderdale, D. S., Knutson, K. L., Yan, L. L., Liu, K., & Rathouz, P. J. (2008). Sleep
459 duration: How well do self-reports reflect objective measures? The CARDIA Sleep
460 Study. *Epidemiology*, 19(6), 838–845.
461 <http://doi.org/10.1097/EDE.0b013e318187a7b0.Sleep>
- 462 Laurent, C. M., Green, J. M., Bishop, P. A., Sjøkvist, J., Schumacher, R. E., Richardson,
463 M. T., & Curtner-Smith, M. (2011). A practical approach to monitoring recovery:
464 Development of a perceived recovery status scale. *Journal of Strength and*
465 *Conditioning Research*, 25(3), 620–628.
- 466 Mah, C. D., Mah, K. E., Kezirian, E. J., & Dement, W. C. (2011). The effects of sleep
467 extension on the athletic performance of collegiate basketball players. *Sleep*, 34(7),
468 943–950. <http://doi.org/10.5665/sleep.1132>
- 469 McLean, B. D., Coutts, A. J., Kelly, V., McGuigan, M. R., & Cormack, S. J. (2010).
470 Neuromuscular, endocrine, and perceptual fatigue responses during different length
471 between-match microcycles in professional rugby league players. *International*
472 *Journal of Sports Physiology and Performance*, 5(3), 367–383.

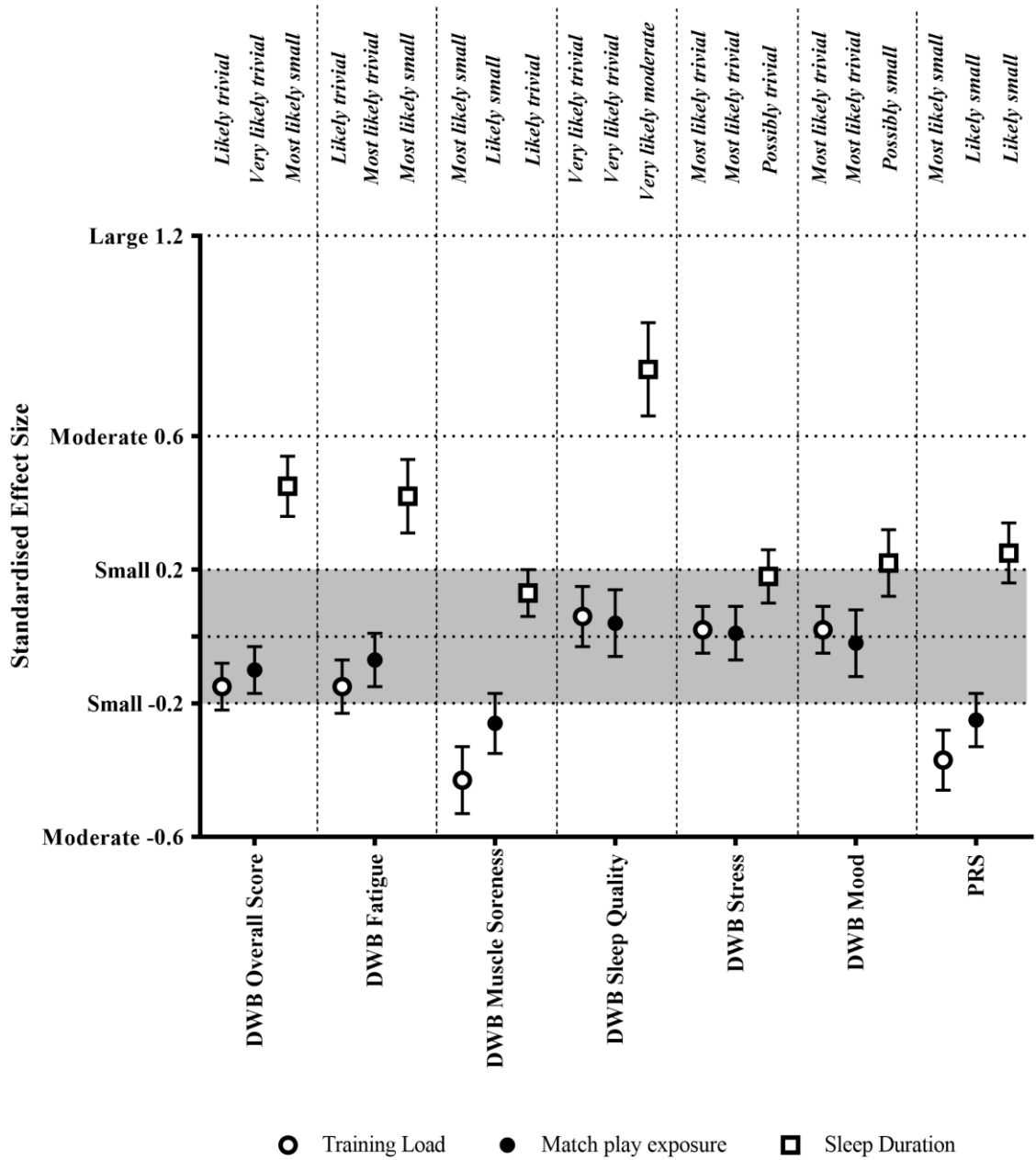
- 473 Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., ... Urhausen, A.
474 (2013). Prevention, diagnosis and treatment of the overtraining syndrome: Joint
475 consensus statement of the European College of Sport Science and the American
476 College of Sports Medicine. *Medicine & Science in Sports & Exercise*, 45(1), 186–
477 205. <http://doi.org/10.1249/MSS.0b013e318279a10a>
- 478 Montgomery, P. G., & Hopkins, W. G. (2013). The effects of game and training loads on
479 perceptual responses of muscle soreness in Australian Football. *International Journal*
480 *of Sports Physiology and Performance*, 8(3), 312–318. <http://doi.org/2012-0181> [pii]
- 481 Mountjoy, M., Armstrong, N., Bizzini, L., Blimkie, C., Evans, J., Gerrard, D., ... Van
482 Mechelen, W. (2008). IOC consensus statement: “Training the elite child athlete.”
483 *British Journal of Sports Medicine*, 42(3), 163–164.
484 <http://doi.org/10.1136/bjism.2007.044016>
- 485 Noon, M. R., James, R. S., Clarke, N. D., Akubat, I., & Thake, C. D. (2015). Perceptions
486 of well-being and physical performance in English elite youth footballers across a
487 season. *Journal of Sports Sciences*, 33(20), 2106–2115.
488 <http://doi.org/10.1080/02640414.2015.1081393>
- 489 Oginska, H., & Pokorski, J. (2006). Fatigue and mood correlates of sleep length in three
490 age-social groups: School children, students, and employees. *Chronobiology*
491 *International*, 23(6), 1317–1328. <http://doi.org/10.1080/07420520601089349>
- 492 Phibbs, P., Roe, G., Jones, B., Read, D., Darrall-Jones, J., Weakley, J., & Till, K. (2017).
493 Validity of daily and weekly self-reported training load measures in adolescent
494 athletes. *Journal of Strength and Conditioning Research*, 31(4), 1121–1126.
495 <http://doi.org/10.1519/JSC.0000000000001708>
- 496 Pilcher, J. J., Ginter, D. R. ., & Sadowsky, B. (1997). Sleep quality versus sleep quantity:
497 Relationships between sleep and measures of health, well-being and sleepiness in

- 498 college students. *Journal of Psychosomatic Research*, 42(6), 583–596.
 499 [http://doi.org/10.1016/S0022-3999\(97\)00004-4](http://doi.org/10.1016/S0022-3999(97)00004-4)
- 500 Prather, A. A., Janicki-Deverts, D., Hall, M. H., & Cohen, S. (2015). Behaviorally assessed
 501 sleep and susceptibility to the common cold. *Sleep*, 38(9), 1353–1359.
- 502 Putlur, P., Foster, C., Miskowski, J. A., Kane, M. K., Burton, S. E., Scheett, T. P., &
 503 McGuigan, M. R. (2004). Alteration of immune function in women collegiate soccer
 504 players and college students. *Journal of Sports Science and Medicine*, 3(4), 234–243.
- 505 Rowbottom, D. G. (2000). Periodization of training. In W. E. Garrett & D. T. Kirkendall
 506 (Eds.), *Exercise and Sport Science* (pp. 499–514). Philadelphia: Lippincott, Williams
 507 and Wilkins.
- 508 Roy, A. (2006). Estimating correlation coefficient between two variables with repeated
 509 observations using mixed effects model. *Biometrical Journal*, 48(2), 286–301.
 510 <http://doi.org/10.1002/bimj.200510192>
- 511 Saw, A. E., Main, L. C., & Gastin, P. B. (2015). Monitoring athletes through self-report:
 512 Factors influencing implementation. *Journal of Sports Science and Medicine*, 14(1),
 513 137–146. <http://doi.org/10.1519/JSC.0000000000000499>
- 514 Saw, A. E., Main, L. C., & Gastin, P. B. (2016). Monitoring the athlete training response:
 515 Subjective self-reported measures trump commonly used objective measures: A
 516 systematic review. *British Journal of Sports Medicine*, 50(5), 281–291.
 517 <http://doi.org/10.1136/bjsports-2015-094758>
- 518 Sawczuk, T., Jones, B., Scantlebury, S., & Till, K. (2018). Relationships between training
 519 load, sleep duration, and daily wellbeing and recovery measures in youth athletes.
 520 *Pediatric Exercise Science*, epub ahead of print.
- 521 Scantlebury, S., Till, K., Sawczuk, T., Phibbs, P., & Jones, B. (2017). The validity of
 522 retrospective session-rating of perceived exertion to quantify training load in youth

- 523 athletes. *Journal of Strength and Conditioning Research*, epub ahead of print.
 524 <http://doi.org/10.1519/JSC.0000000000002099>
- 525 Siesmaa, E. J., Blitvich, J. D., & Finch, C. F. (2011). A systematic review of the factors
 526 which are most influential in children's decisions to drop out of organised sport. In A.
 527 D. Farelli (Ed.), *Sport Participation: Health Benefits, Injuries and Psychological*
 528 *Effects* (pp. 1–45). Hauppauge, NY: Nova Science.
- 529 Stults-Kolehmainen, M. A., Bartholomew, J. B., & Sinha, R. (2014). Chronic
 530 psychological stress impairs recovery of muscular function and somatic sensations
 531 over a 96-hour period. *Journal of Strength and Conditioning Research*, 28(7), 2007–
 532 2017. <http://doi.org/10.1519/JSC.0000000000000335>
- 533 Taylor, R., Sanders, D., Myers, T., Abt, G., Taylor, C. A., & Akubat, I. (2018). The dose-
 534 response relationship between training load and aerobic fitness in academy rugby
 535 union players. *International Journal of Sports Physiology and Performance*, epub
 536 ahead of print. <http://doi.org/10.1123/ijsp.2017-0121>
- 537 Thornton, H. R., Delaney, J. A., Duthie, G. M., & Dascombe, B. J. (2017). Importance of
 538 various training load measures on injury incidence of professional rugby league
 539 athletes. *International Journal of Sports Physiology and Performance*, epub ahead of
 540 print. <http://doi.org/10.1123/ijsp.2016-0326>
- 541 Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W.
 542 (2015). Monitoring fatigue during the in-season competitive phase in elite soccer
 543 players. *International Journal of Sports Physiology and Performance*, 10(8), 958–
 544 964.
- 545 Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W.
 546 (2017). The influence of changes in acute training load on daily sensitivity of morning
 547 measured fatigue variables in elite soccer players. *International Journal of Sports*

- 548 *Physiology and Performance*, 12(S2), S2107–S2113.
- 549 Tuomilehto, H., Vuorinen, V. P., Penttilä, E., Kivimäki, M., Vuorenmaa, M., Venojärvi,
550 M., ... Pihlajamäki, J. (2017). Sleep of professional athletes: Underexploited potential
551 to improve health and performance. *Journal of Sports Sciences*, 35(7), 704–710.
552 <http://doi.org/10.1080/02640414.2016.1184300>
- 553 Watson, A., Brickson, S., Brooks, A., & Dunn, W. (2016). Subjective well-being and
554 training load predict in-season injury and illness risk in female youth soccer players.
555 *British Journal of Sports Medicine*, epub ahead of print.
- 556 Williams, S., West, S., Cross, M. J., & Stokes, K. A. (2016). A better way to determine the
557 acute:chronic workload ratio? *British Journal of Sports Medicine*.
- 558
- 559

560 **Figure 1:** The influence of training load, exposure to match play and sleep duration on the
 561 overall DWB score, its individual subscales and PRS. Data are presented as effect size with
 562 90% confidence intervals, shaded area denotes smallest worthwhile change.



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