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1 **Relationships between training load, sleep duration, and daily wellbeing and recovery measures**
2 **in youth athletes**

3 Running head: Training load, sleep and wellbeing relationships

4

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22

23 **Abstract**

24 **Purpose:** To assess the relationships between training load, sleep duration and three daily wellbeing,
25 recovery and fatigue measures in youth athletes. **Methods:** Fifty-two youth athletes completed three
26 maximal countermovement jumps (CMJ), a daily wellbeing questionnaire (DWB), the Perceived
27 Recovery Status scale (PRS), and provided details on their previous day's training loads (training) and
28 self-reported sleep duration (sleep) on four weekdays over a seven week period. Partial correlations,
29 linear mixed models and magnitude-based inferences were used to assess the relationships between
30 the predictor variables (training; sleep) and the dependent variables (CMJ; DWB; PRS). **Results:**
31 There was no relationship between CMJ and training ($r=-0.09; \pm 0.06$) or sleep ($r=0.01; \pm 0.06$). The
32 DWB was correlated with sleep ($r=0.28; \pm 0.05$, *small*), but not training ($r=-0.05; \pm 0.06$). The PRS
33 was correlated with training ($r=-0.23; \pm 0.05$, *small*), but not sleep ($r=0.12; \pm 0.06$). The DWB was
34 sensitive to low sleep ($d=-0.33; \pm 0.11$) relative to moderate, PRS was sensitive to high ($d=-0.36;$
35 ± 0.11) and low ($d=0.29; \pm 0.17$) training relative to moderate. **Conclusions:** The PRS is a simple tool
36 to monitor the training response, but DWB may provide a greater understanding of the athlete's
37 overall wellbeing. The CMJ was not associated with the training or sleep response in this population.

38

39

40 **Introduction**

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

50

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

64

65 Alongside perceptions of wellbeing, it may be useful to collect measures objectively or subjectively
66 evaluating an athlete's fatigue and recovery status. Consequently, alternative monitoring methods (e.g.
67 the Perceived Recovery Status Scale (PRS; 16) or CMJ) should be considered. The PRS is a 0-10

68 scale, where athletes are asked to rate their recovery using descriptors anchored to numerical values
69 similar to the Borg category-ratio 10 scale (6). It has shown good sensitivity to both aerobic and
70 resistance based exercise protocols (19, 45), but no study exists within applied sport settings. It is
71 important that this environment is considered so its association with uncontrolled training loads can
72 be confirmed. The CMJ, a surrogate measure of neuromuscular fatigue, has received significant
73 support within the literature as a fatigue measure (24, 37, 40, 47). However, although recent studies
74 have demonstrated its association with training load in elite adult soccer players on both a jump mat
75 (47) and a force plate (40), no relationship was found when it was tested in elite youth soccer players,
76 possibly due to the basic statistical methods used (21). Despite conflicting findings between the
77 studies, it is work in professional soccer using a force plate (40) which provides the most practically
78 interesting findings. This work compared high, medium and low training loads showing expected
79 changes in CMJ metrics over the following 90 hours. As would be expected, medium and high loads
80 exhibited greater changes than low loads, showing the association between training loads and CMJ,
81 and a replication of this more advanced statistical analysis could be beneficial to show the relationship
82 between differing levels of training load and CMJ, PRS and daily wellbeing measures in a youth sport
83 athlete cohort.

84

85 In addition to training load, sleep has previously shown relationships with changes in mood, and
86 injury and illness risk, as well as being implicated with the overtraining syndrome (3, 25, 26, 30).
87 Previous studies have eschewed the use of self-reported sleep duration as a predictor of outcome
88 measures due to its lack of validity compared to actigraphy (11, 18), instead using a measure of sleep
89 quality within their wellbeing questionnaires (1, 10, 37, 47). However, the validity of subjective sleep
90 quality measures has also been questioned when compared to objective measures (17). Furthermore,
91 as some individuals complain of poor sleep quality when their objective sleep measures are normal
92 and others indicate they have had good quality sleep when their objective sleep measures suggest
93 otherwise (17), it is arguable that the individual's perceptions of sleep, in terms of duration and
94 quality, may be more important than the objective measure itself. Isolating the impact of sleep as a
95 sleep quality subscale also ensures it is difficult to identify whether the training load itself or the

96 circumstances arising from the prescribed training load (e.g. early/late training times and travel time
97 to/from training sessions affecting sleep habits) result in changes in perceptions of sleep quality and
98 wellbeing. The inclusion of self reported sleep duration in analyses could therefore add to the
99 understanding of factors affecting different wellbeing measures, particularly as some of these
100 measures already include sleep quality subscales but no information relating to sleep duration.

101

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

108

109 **Methods**

110 *Participants*

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

120

121 *Study Procedures*

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

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

128

129 The between day reliability, as a coefficient of variation, and smallest worthwhile change of DWB
130 and PRS were calculated using two time points 7 days apart. Each datum point was preceded by a day
131 of rest and was selected so that the difference in sleep duration was as small as possible. The between-
132 day reliability for DWB was 11.7% and PRS was 8.5%. The smallest worthwhile changes were 6.2%
133 and 4.9% respectively for DWB and PRS. Participants rated each session for the 24 hour training load
134 using the Borg category ratio-10 scale (6), choosing the respective descriptor. The descriptor was
135 converted to the appropriate RPE number and multiplied by the session duration (also provided by the
136 participant) to provide the sessional RPE (s-RPE) and the sum of all s-RPE's on a single day gave the
137 daily training load. The temporal robustness of the s-RPE method has previously been confirmed over
138 24 hours (32, 44).

139

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

151

152 *Statistical Analyses*

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

170

171 Results were analysed for practical significance using magnitude-based inferences (16). The threshold
172 for a change to be considered practically important (the smallest worthwhile change) was set as 0.2 x
173 observed between participant standard deviation, based on Cohen's *d* effect size (ES) principle (15).
174 Thresholds ES were set as: 0.2 *small*; 0.6 *moderate*; 1.2 *large*, 2.0 *very large*. Thresholds for
175 correlations (*r*) were set as: 0.1 *small*; 0.3 *moderate*; 0.5 *large*; 0.7 *very large*; 0.9 *almost perfect*. The
176 probability that the magnitude of change was greater than the smallest worthwhile change was rated
177 as: $<0.5\%$ *almost certainly not*; 0.5-5% *very unlikely*; 5-25% *unlikely*; 25-75% *possibly*; 75-95%
178 *likely*; 95-99.5% *very likely*; $>99.5\%$ *almost certainly* (16). All data are reported as mean \pm standard

179 deviation. ES and correlations are reported ES and r ; \pm 90% confidence intervals, and the direction of
180 the association (positive or negative) is reported in the text.

181

182 **Results**

183

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

185

186 ** INSERT TABLE 1 HERE **

187

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

192

193 ** INSERT TABLE 2 HERE **

194

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

203

204 ** INSERT FIGURES 1 & 2 HERE **

205

206 **Discussion**

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

213

214 The key finding of this study is that DWB showed no relationship with training load. These results
215 conflict with research in elite adult team sport athletes indicating that training load does affect DWB
216 (1, 10, 47), but agree with findings in adolescent athletes where training load was not related to the
217 recovery-stress balance as measured by the Recovery Stress Questionnaire for Athletes (13). It is
218 possible that this is due to a difference in the relative intensity of stressors between the two
219 populations. Adolescent athletes have a unique set of social, educational and maturational
220 circumstances to navigate (28), which may be of greater relative importance to their wellbeing than
221 training for their sport alone. In addition to these other stressors, the intensity of training at an
222 adolescent level is significantly lower than at the elite adult level (2, 4, 35, 36). The results may
223 indicate that academic and social stresses are of greater importance to adolescent athletes' wellbeing
224 than training load, but more research is needed to confirm the predictive qualities of these stressors on
225 the youth athletes' wellbeing.

226

227 The association of sleep duration, particularly low levels of sleep, with DWB at the expense of
228 training load is unique to this study. Although it is well known that sleep deprivation results in lower
229 mood (30) and that increased training loads are linked with reduced sleep (41), no study has yet
230 controlled for the effects of sleep duration on DWB when assessing the impact of other predictors.

231 The average sleep duration of 7.3 hours reported in this study falls below the National Sleep
232 Foundation's recommendations of 8-10 hours per night for adolescents (14). Given that these
233 guidelines don't account for the extra sleep required by youth sport athletes relative to the average
234 population (5), it is possible that insufficient sleep, and by extension recovery, is a greater issue for

235 youth athletes than the training load experienced. This, in combination with the academic and social
236 stressors influencing sleep duration (31) could explain why DWB has a greater association with sleep
237 than training load.

238

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

254

255 Our finding that CMJ was not related to training load conflicts with the literature showing training
256 load to result in a decrease in CMJ in elite adult athletes (40, 47), but agrees with that in elite youth
257 soccer players (21). It has previously been argued that adolescent athletes train at a lower intensity
258 than elite athletes (2, 4, 35, 36), which could result in lower neuromuscular fatigue and a reduced need
259 for a neuromuscular fatigue test such as the CMJ. The agreement of our results with a previous study
260 in a similar cohort using the same equipment (21) provides further evidence within the literature that
261 training load (within the ranges presented in this study) does not affect CMJ performance in this
262 population. The lack of association between CMJ and sleep duration contradicts previous literature

263 suggesting that sleep deprivation and extension can have positive and negative effects on
264 neuromuscular performance respectively (20, 46). However, given the training stimulus in this study
265 may not have been intense enough to reduce neuromuscular function and the sleep duration shown in
266 this study were reasonably uniform in nature, it is unsurprising that there was no difference in
267 neuromuscular recovery attributable to the duration of sleep experienced. Alternatively, the wide
268 variability in the effect of training load on CMJ ($r = 0.09; \pm 0.06$) could be due to the inherent
269 variation in motivation shown between and within participants over the duration of this study, which
270 may have resulted in participants not always providing their best effort. Regardless, our results
271 indicate that CMJ is not responsive to training load or sleep length in this population.

272

273 *Limitations*

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

291 shown that a decline in perceptions of wellbeing does impact on training performance in elite athletes
292 (9, 22), however such an effect may not be present in youth athletes due to their unique circumstances
293 (28). Future research should therefore attempt to quantify whether there is a relationship between
294 perceptions of wellbeing and competitive performance in youth sport athletes.

295

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

308

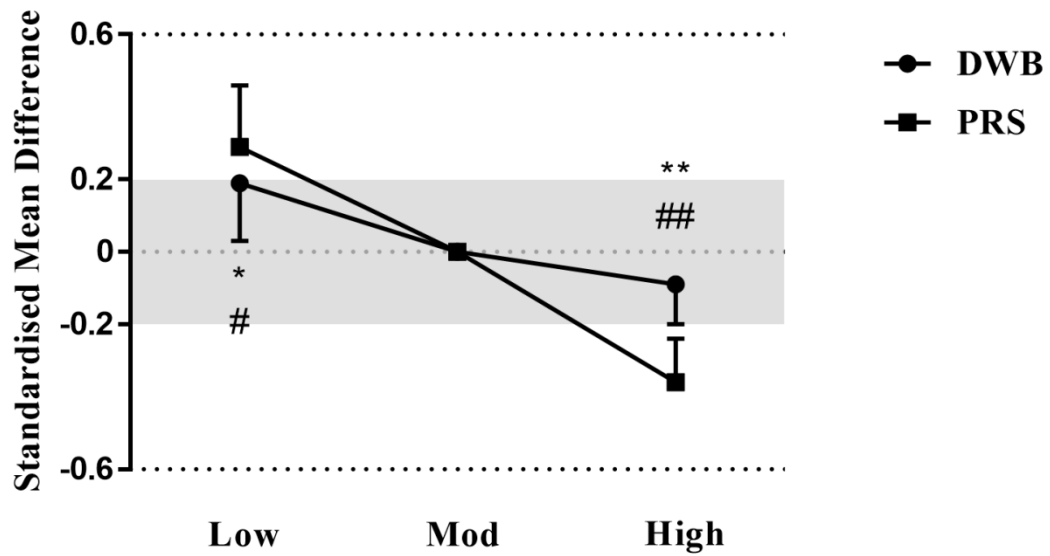
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- 419



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421 **Figure 1:** Visual representation of pairwise comparisons for the differing effect of high, moderate and

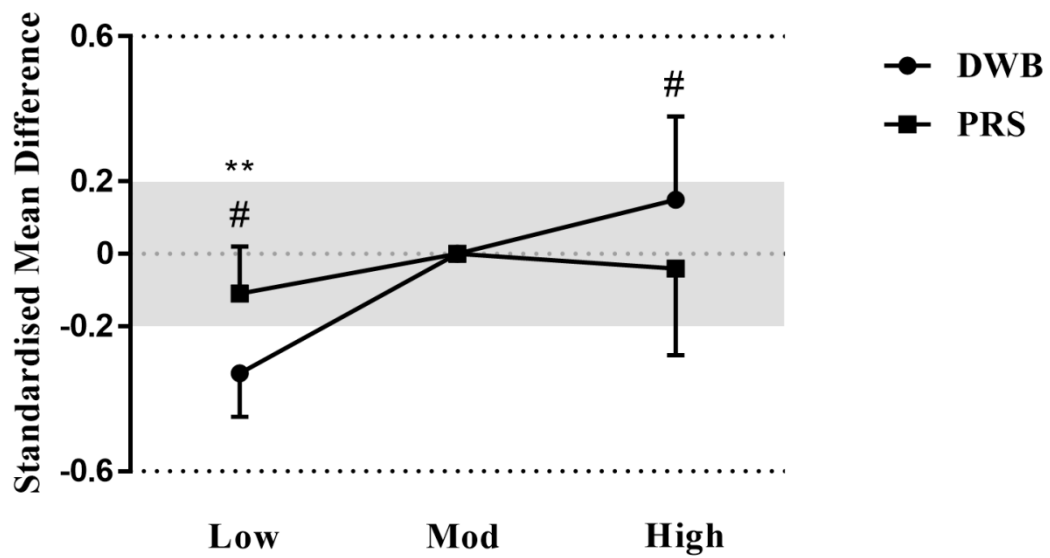
422 low training loads on DWB and PRS. Data are presented as mean difference relative to moderate

423 training load \pm 90% confidence intervals. Shaded area represents smallest worthwhile change .

424 Asterixes and hashtags denote likelihood that the difference in effect is greater than the smallest

425 worthwhile change: * likely; ** very likely for DWB; # likely; ## very likely for PRS.

426



427

428 **Figure 2:** Visual representation of pairwise comparisons for the differing effect of high, moderate and

429 low sleep duration on DWB and PRS. Data are presented as mean difference relative to moderate

430 sleep length \pm 90% confidence intervals. Shaded area represents smallest worthwhile change.

431 Asterixes and hashtags denote likelihood that the difference in effect is greater than the smallest

432 worthwhile change: ** very likely for DWB; # likely for PRS.

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434

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

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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 \pm 90% confidence intervals.

	Correlation Coefficient	Magnitude	Descriptor
DWB			
Training Load	-0.05; \pm 0.06	<i>Trivial</i>	<i>Likely</i>
Sleep Duration	0.01; \pm 0.06	<i>Trivial</i>	<i>Very Likely</i>
PRS			
Training Load	-0.23; \pm 0.05	<i>Small</i>	<i>Most Likely</i>
Sleep Duration	0.12; \pm 0.06	<i>Small</i>	<i>Possibly</i>
CMJ			
Training Load	-0.09; \pm 0.06	<i>Trivial</i>	<i>Possibly</i>
Sleep Duration	0.01; \pm 0.06	<i>Trivial</i>	<i>Very Likely</i>