

1 **The influence of changes in acute training load on daily sensitivity of morning-**
2 **measured fatigue variables in elite soccer players.**

3 RT. Thorpe^{1,2}, AJ. Strudwick^{1,2}, M. Buchheit^{4,5}, G. Atkinson³, B. Drust², W. Gregson²

4 ¹ Medicine and Science Department, Manchester United, Manchester, UK

5 ² Football Exchange, Research Institute for Sport and Exercise Sciences, Liverpool John

6 Moores University, UK

7 ³ Health and Social Care Institute, Teesside University, UK

8 ⁴ Sport Science Department, Myorobie Association, Montvalezan, France

9 ⁵ Performance Department, Paris Saint Germain FC

10

11 Corresponding Author:

12 Robin T. Thorpe

13 Manchester United, Aon Training Complex, Birch Road off Isherwood Road, Carrington,

14 Manchester M31 4BH

15 E-mail: robin.thorpe@manutd.co.uk

16 Key Words-Training, Performance, Wellness, Recovery

17

18 Word count: 3653

19 Abstract word count: 250

20 Number of figures: 0

21 Number of tables: 7

22

23 **The influence of changes in acute training load on daily sensitivity of morning-**
24 **measured fatigue variables in elite soccer players**

25 **Abstract**

26 **Purpose** To determine the sensitivity of a range of potential fatigue measures to daily
27 training load accumulated over the previous two, three and four days during a short in-season
28 competitive period in elite senior soccer players (n=10).

29 **Methods** Total high-speed running distance, perceived ratings of wellness (fatigue, muscle
30 soreness, sleep quality), counter-movement jump height (CMJ), submaximal heart rate
31 (HRex), post-exercise heart rate recovery (HRR) and heart rate variability (HRV: Ln rMSSD)
32 were analysed during an in-season competitive period (17 days). General linear models were
33 used to evaluate the influence of two, three and four day total high-speed running distance
34 accumulation on fatigue measures.

35 **Results** Fluctuations in perceived ratings of fatigue were correlated with fluctuations in total
36 high-speed running distance accumulation covered on the previous 2-days ($r=-0.31$; small), 3
37 -days ($r=-0.42$; moderate) and 4-days ($r=-0.28$; small) ($p<0.05$). Changes in HRex ($r=0.28$;
38 small; $p= 0.02$) were correlated with changes in 4-day total high-speed running distance
39 accumulation only. Correlations between variability in muscle soreness, sleep quality, CMJ,
40 HRR% and HRV and total high-speed running distance were negligible and not statistically
41 significant for all accumulation training loads.

42 **Conclusions** Perceived ratings of fatigue and HRex were sensitive to fluctuations in acute
43 total high-speed running distance accumulation, although, sensitivity was not systematically
44 influenced by the number of previous days over which the training load was accumulated.
45 The present findings indicate that the sensitivity of morning-measured fatigue variables to
46 changes in training load is generally not improved when compared with training loads
47 beyond the previous days training.

48

49 Introduction

50

51 The locomotor demands of elite soccer have progressively increased in recent years.^{1,2} Since
52 leading teams are also required to compete in a high number of matches over the course of
53 season,³ implementation of effective recovery strategies are paramount in order to avoid the
54 debilitating effects associated with overtraining and injury.⁴ Increasing attention in the
55 literature has therefore focused upon evaluating the effectiveness of a range of monitoring
56 tools which may serve as valid indicators of fatigue status of athletes.⁵ For the purpose of
57 this manuscript, fatigue will be defined as an inability to complete a task that was once
58 achievable within a recent time frame.⁶

59 Recent research has examined the sensitivity of potential measures of fatigue to daily
60 fluctuations in training load in Australian Rules Football (AFL).^{7,8} In AFL players, perceived
61 ratings of wellness,^{7,8} sub-maximal heart rate (HR_{ex})⁷ and an index (LnSD1) of vagal-
62 related heart rate variability (HRV)⁷ were sensitive to the fluctuations in daily training load
63 during a pre-season training period. Similarly, in elite soccer players competing in the
64 English Premier League (EPL),⁹ both rating of perceived fatigue and vagal related HRV
65 measure Ln rMSSD were most sensitive to the previous days fluctuations in training load
66 experienced during the in-season competition period. Furthermore, in the same population,
67 only perceived ratings of wellness were sensitive to within-week fluctuations in match and
68 training load during typical in-season competition weeks.¹⁰ Collectively, these findings
69 demonstrate that these measures, particular perceived ratings of wellness, show promise as
70 acute, simple, non-invasive assessments for tracking the fatigue status of elite team sport
71 athletes.

72 Physiological adaptation to training is the culmination of repeated daily applications of
73 training load.¹¹ The level of fatigue experienced by an athlete at any one point in time is
74 therefore unlikely to purely reflect the load incurred from the previous day's activity,⁹ but
75 rather the load accumulated from a number of training days. Indeed high-intensity exercise
76 and eccentric type activity leads to increases in muscle soreness that may be present for up to
77 72-hours following the exercise stress.^{12,13} In line with such observations, Buchheit (2014)
78 recently suggested that HRV indices, used as an indicator of the athletes training status, may
79 be more sensitive to changes in training loads when averaged across 7-days compared to a
80 single daily measurement.¹⁴ Similarly, reductions and increases in heart rate recovery (HRR)
81 have been seen in response to weekly increases in training load and performance in
82 physically active subjects and elite cyclists respectively.^{15,16}

83 Recent observations in elite senior soccer players have demonstrated that potential fatigue
84 measures, particularly perceived ratings of wellness, were sensitive to within-week
85 fluctuations in match and training load during typical competition weeks.⁹ Changes in these
86 measures across the training week may, therefore, to some extent reflect the periodised
87 training load incurred over a number of the preceding days and not solely the previous days
88 training. It is possible therefore, that the relationship between such potential markers of
89 fatigue and training load may vary as a function of the number of accumulated training days.
90 The response to a single training session may not have the same physiological effect or
91 magnitude compared to multiple training sessions performed over a short period of time.
92 Therefore, our aim was to determine whether the sensitivity of a range of potential fatigue
93 measures would vary when compared to the training load accumulated over the previous two,
94 three or four days during a short in-season competitive phase in elite soccer players. These
95 data would enable comparison with previous observations in the same population which

96 examined the sensitivity of the same measures to the previous day's fluctuations in training
97 load.⁸

98 **Methods**

99 **Subjects**

100 Data were collected from 10 senior outfield soccer players (19.1±0.6 years; 1.84±0.7m;
101 75.4±7.6 kg) competing in the EPL over a 17-day period (February) during the in-season
102 competition phase.

103

104 **Design**

105

106 Players took part in normal team training throughout the 17-day period as prescribed by the
107 coaching staff. This included two competitive reserve team home matches (day 1 and 10),
108 three rest days (day 6, 11 and 16) and twelve training sessions. All players were fully
109 familiarised with the fatigue assessments in the weeks prior to completion of the main
110 experimental trials. Fatigue measures were assessed each morning prior to the players
111 commencing normal training. Perceived ratings of wellness measurements were assessed
112 every day during the 17-day period. Physiological measurements were assessed every day
113 with the exception of match and rest days. Each day players arrived at the training ground
114 laboratory having refrained from caffeine intake at least 12-hours prior to each assessment
115 point. All assessments were conducted at the same time of the day in order to avoid the
116 circadian variation in body temperature.¹⁷ Players were not allowed to consume fluid at any
117 time during the fatigue assessments. The study was approved by the Liverpool John Moores
118 University Ethics Committee. All players provided written informed consent. Prior to
119 inclusion into the study, players were examined by the club physician and were deemed to be
120 free from illness and injury.

121

122 **Methodology**

123

124 Training Load Assessment Individual player daily training and match load was monitored
125 throughout the 17-day assessment period. Each player was also monitored during each
126 training session and match using a portable global positioning system (GPS) technology
127 (GPSports SPI Pro X 5 Hz, Canberra, Australia). This type of system has previously been
128 shown to provide valid and reliable estimates of instantaneous velocity during acceleration,
129 deceleration, and constant velocity movements during linear, multidirectional and soccer-
130 specific activities^{18,19}. All devices were activated 15-min before the data collection to allow
131 acquisition of satellite signals.²⁰ The minimum acceptable number of available satellite
132 signals was 8 (range 8-11).²¹ Players wore the same GPS device for each session in order to
133 avoid inter-unit error²¹. Based on GPS data, locomotive speed above the threshold of 14.8
134 km/h was classified as high-speed running. Total high-speed running distance was employed
135 in the present study as an index of training and match load due to its frequent inclusion in
136 attempts to quantify the load incurred by elite players during training and match-play.²²
137 However, high speed running will underestimate the true load incurred by the athlete since it
138 does not account for the stress associated with the frequent accelerations and decelerations
139 which occur during soccer.²³ It should be noted, however, that initial analysis in the present

140 study highlighted a large correlation ($r=0.57$) between total high-speed running distance and
141 session ratings of perceived exertion (sRPE) which has previously been used as a global
142 indicator of internal load in soccer players.²⁴

143

144 Perceived Ratings of Wellness

145 A psychometric questionnaire was used daily prior to any training or exercise to assess
146 general indicators of player wellness.^{9,10} The questionnaire comprised three questions
147 relating to perceived sleep quality (coefficient of variation 13%), muscle soreness (coefficient
148 of variation 9%) and fatigue (coefficient of variation 12%).⁹ Each question scored on a
149 seven-point Likert scale [scores of 1-7 with 1 and 7 representing very, very poor (negative
150 state of wellness) and very, very good (positive state of wellness) respectively].

151 Countermovement Jump Countermovement jump⁹(coefficient of variation 4%)⁹ (CMJ)
152 performance was evaluated using a jump mat (Fusion Sport, Queensland, Australia).
153 Participants performed five CMJ efforts in total, two practice and three assessment jumps
154 ensuring the hands were affixed to the hips throughout the jump. The highest jump was used
155 as the criterion measure of performance.

156 Heart rate indices Players completed an indoor submaximal 5-min cycling (Keiser,
157 California, USA) /5-min recovery test as part of the warm up prior to commencing every
158 training session.⁹ All players were assessed together at a fixed exercise intensity of 130 watts
159 (85 rpm). The present intensity was selected to minimize anaerobic energy contribution²⁵ and
160 to permit a rapid return of heart rate to baseline for short-term HRV measurements. On
161 completion of exercise the players remained seated in silence for 5-min. HRV expressed as
162 the square root of the mean of the sum of squares of differences between adjacent normal R-
163 R intervals (rMSSD, coefficient of variation 28%)⁹ and the natural logarithm of the rMSSD
164 (Ln rMSSD, coefficient of variation 10%)⁹ were calculated as previously described²⁵ using
165 Polar software (Polar Precision Performance SW 5.20, Polar Electro, Kemple, Finland). Heart
166 rate recovery (HRR) expressed as the absolute (HRR, coefficient of variation 14%)⁹ and
167 relative (%HRR, coefficient of variation 10%)⁹ change in HR between the final 30-sec
168 (average) of the 5-min cycling test and 60 sec after cessation of exercise were calculated as
169 previously described.^{9,16,25}

170

171 Statistical Analysis

172 Data were analysed with general linear models, which allowed for the fact that data were
173 collected within-subjects over time.²⁶ Recently, step-wise regression approaches have been
174 criticised for reliable variable selection in a model.^{27,28} Our added problem was the predicted
175 high multicollinearity between the various independent variables in our study. Therefore, we
176 used a combination of expert knowledge regarding which variables hold superior
177 practical/clinical importance²⁸ and a multicollinearity correlation coefficient of >0.5 for initial
178 variable selection. Total high-speed running distance was selected in order to provide an
179 indication of training and match load (independent variable) in the present study. We then
180 quantified the relationships between the various predictors and outcomes using model I
181 (unadjusted model) and model II (fully adjusted model from which partial correlation
182 coefficients and associated 95% confidence intervals for each predictor could be derived). To
183 calculate acute training load accumulation, the rolling mean 2, 3 and 4-day total high-speed
184 running distances were then related to the subsequent day's morning-measured fatigue

185 variables. The following criteria were adopted to interpret the magnitude of the correlation (r)
186 between test measures: <0.1 trivial, 0.1 to 0.3 small, 0.3 to 0.5 moderate, 0.5 to 0.7 large, 0.7
187 to 0.9 very large, and 0.9 to 1.0 almost perfect.²⁹ The level of statistical significance was set
188 at $p < 0.05$ for all tests.

189

190 **Results**

191

192 Partial correlations, least squares regression slope (B) and significance for the relationship
193 between total high-speed running distance (over 2-4 days) and morning-measured fatigue
194 variables are shown in Tables 1-7. Absolute variability in training load and fatigue measures
195 over the 17 day period can be viewed in a recent publication⁹ All players competed in both
196 matches during the 17-day period with a median of 79 min playing time per player (range =
197 32-93 min). Variability in ratings of perceived fatigue were correlated to variability in total
198 high-speed running distance covered on the previous 2, 3 and 4 days ($p < 0.05$; Table 1).
199 Small-to-moderate correlations were observed for 2 ($r = -0.31$), 3 ($r = -0.42$) and 4 ($r = -0.28$)
200 day cumulative total high-speed running distance. Correlations between variability in
201 perceived sleep quality and muscle soreness and total high-speed running distance across all
202 days were trivial to small and not statistically significant (Table 2 and 3).

203 Insert Tables 1-3 here

204 Correlations between variability in CMJ and total high-speed running distance across all days
205 were trivial to small and not statistically significant (Table 4).

206 Insert Table 4 here

207 Correlations between variability in HRex and total high-speed running distance across all
208 days were trivial to small and only statistically significant with 4-day cumulative total high-
209 speed running distance ($r = 0.28$; $p = 0.02$; Table 5).

210 Insert Table 5 here

211 Correlations between variability in HRR (%) and Ln rMSSD and total high-speed running
212 distance for all days were trivial and not statistically significant (Table 6 and 7).

213 Insert Tables 6 and 7 here

214 **Discussion**

215

216 The aim of the current study was to determine whether the sensitivity of a range of morning-
217 measured fatigue variables to changes in training load was influenced by the number of
218 previous days over which the training load was accumulated in elite soccer players. When
219 compared with previous data published on the current population, the present findings
220 indicate that the sensitivity of morning-measured fatigue measures to changes in training load
221 is generally not improved when compared with training loads beyond the previous days
222 training.⁹

223 The use of simple perceived ratings of wellness is an efficient and practical approach to
224 determining the fatigue status of elite team sport athletes.^{8-10,30} Previous observations on elite
225 soccer players showed a moderate-to-strong significant correlation between the players
226 perceived rating of fatigue and the previous days total high-speed running distance ($r=-0.51$;
227 $p<0.001$).⁹ Furthermore, the slope of the regression model indicated that every ~400m
228 increase in total high-speed running distance led to a one unit decrease (For example a player
229 may change from very poor level of fatigue to very, very poor level of fatigue following an
230 additional ~400m total high-speed running distance) in fatigue with 37 % of the variance in
231 training load explained by all the statistically significant predictors.⁹ In contrast, the current
232 findings demonstrate that the sensitivity of morning-measured perceived fatigue, to changes
233 in training load is reduced from significantly moderate to significantly small ($r=-0.42$ to -
234 0.28) when compared with the training load observed beyond the previous days training.⁹
235 Indeed, the variance in training load explained by all the statistically significant predictors
236 decreased to 15% when training load was accumulated over a number (2-4) of days,
237 highlighting the importance of immediately preceding load in elite soccer players. This
238 apparent importance of the previous days training load on morning-measured fatigue may to
239 some extent be explained by the nature of training cycles undertaken by elite soccer players.
240 During the in-season competition period, players rotate around weekly cycles comprising one
241 to two matches (very high load) interspersed with training sessions (moderate to high load)
242 and recovery sessions.^{22,31,32} This cycle of daily loading peaks and-troughs within a short
243 time frame may, therefore, only lead to changes in fatigue status that are largely
244 representative of the previous days training. The influence of accumulated training load on
245 morning measured perceived fatigue may be more relevant to endurance based sports where
246 load is distributed and sustained over extended training blocks.

247 Small significant correlations have been reported between daily perceived ratings of sleep
248 quality ($r=0.2$) and muscle soreness ($r=0.3$) and the previous days training load during pre-
249 season training in elite AFL players.⁷ In contrast, in EPL players the relationship between
250 daily training load and perceived ratings of sleep quality and muscle soreness were trivial and
251 non-significant.⁹ Furthermore, in the current study, we demonstrate that the magnitude of
252 these relationships are not influenced by the number of days over which training load was
253 accumulated. Muscle soreness has been found to be significantly elevated between 24 and 72-
254 hours following a soccer match^{12,13,33}. Moreover, sleep quality has been seen to decrease
255 around periods of competition.³⁴ In the present study, only two match days were included in
256 the sample of 17-days, consequently, the limited match exposure and training intensity may
257 not have been sufficient to influence muscle soreness and sleep quality. In a previous study
258 from the same population of players, match demands accounted for ~40% of total weekly
259 load, moreover, perceived ratings of wellness were found to be lowest on the day post-match,

260 ¹⁰ further showing the debilitating effects of a match on fatigue status. Indeed, the average
261 daily training load in the current study (RPE-TL 361) is considerably lower than that reported
262 during an AFL pre-season training camp (RPE-TL 746) where daily readings of muscle
263 soreness and sleep quality were associated with changes in load. ⁷ Future work involving a
264 greater frequency of matches is therefore warranted in order to fully examine the influence of
265 changes in loading on morning-measured perceived ratings of muscle soreness and sleep.

266 Previously, in elite soccer players, a small, positive daily correlation was observed ($r=0.23$)
267 between CMJ height and total high-speed running distance suggesting improved performance
268 with increased total high-speed running distance. ⁹ It has been reported that the assessment of
269 neuromuscular function via the use of jump protocols may be impaired up to 72-hours post-
270 match. ^{35,36} However, in the present study, a non-significant trivial to-small relationship was
271 found between changes in CMJ height and total high-speed running distance accumulation
272 over 2-4-days. Collectively, the findings from the current study and those from earlier
273 investigations, ^{9,37} demonstrate that CMJ height is generally insensitive to acute changes in
274 workload in elite soccer players. CMJ height alone may be too crude of a measure in order to
275 detect changes in training load, however, alternative CMJ derived neuromuscular parameters
276 may hold sensitivity to alterations in load irrespective of the limited change in CMJ height.
277 For example, neuromuscular parameters (eccentric, concentric, and total duration, time to
278 peak force/power, flight time:contraction time ratio) derived from CMJ have been found
279 suitable for detection of neuromuscular fatigue. ³⁸ Reductions in 18 different neuromuscular
280 variables were found following a high-intensity fatiguing protocol in college-level team sport
281 athletes. ³⁸ Furthermore, reductions in the flight time contraction time ratio have been found
282 across a season in AFL players indicating sensitivity to increases in load over time. ³⁹ Future
283 research is required to investigate whether alternative measures derived from CMJ are
284 sensitive to changes in training load in elite soccer players.

285 In recent years heart rate (HR) indices (HRV, HRR and HRex) have been used as a popular
286 method to measure variations in the autonomic nervous system (ANS) in an attempt to
287 understand athlete adaptation/fatigue status. ¹⁴ The use of vagal related time domain indices
288 such as Ln rMSSD have been found to have greater reliability and are ideal for assessments
289 over short periods when compared to spectral indices of HRV. ^{40,41} A small significant
290 correlation ($r=-0.2$; $p=0.04$) was found between the daily fluctuations in Ln rMSSD and total
291 high-speed running distance in elite soccer players from an earlier study. ⁹ In this study, the
292 slope of the regression model indicated that every $\sim 300\text{m}$ increase in total high-speed running
293 distance led to a decrease of one unit in HRV i.e. more sympathetic dominance the greater the
294 training load. ^{7,9,42} In the current study, non-significant, trivial correlations were observed
295 between fluctuations in 2, 3 and 4-day total high-speed running distance and changes in
296 morning-measured HRV, implying no additional effect on HRV beyond the previous days of
297 training load. The limited relationships may reflect the low loads incurred by players
298 observed in the current study. Buchheit et al, (2013) found significant daily correlations
299 ($r=0.40$) with a comparable vagal related parameter HRV (Ln SD1) during a pre-season camp
300 in AFL players. ⁷ A possible reason for the small-to-moderate correlation found may be due
301 to the enhanced training load performed by AFL players. ⁷ Another potential reason for the
302 lack of sensitivity observed for HRV in the present study may be due to the inherent variation
303 of this measure. Indeed, based on data derived from endurance sports it is suggested that the
304 use of one single data point could be misleading for practitioners due to the high day-to-day
305 variation in these indices. ⁴³ When data were averaged over a week or using 7-day rolling
306 averages, sensitivity to training load and performance has been improved compared to a
307 single assessment point. A similar observation in young Handball players has also been

308 reported when single monthly assessments were found to have less than 20% sensitivity to
309 training status.⁴⁴ Future work is required to observe whether more frequent measures of
310 HRV improve sensitivity to training load. Furthermore, future research is needed to establish
311 how HRV responds to more extended and sustained periods of training and match load in
312 elite soccer players.

313 In the present study, small significant increases in HRex were associated with increases in 4-
314 days accumulated total high-speed running distance. Contrastingly, Buchheit et al. (2013)
315 found a large negative correlation between daily training load and HRex suggesting a
316 reduction in heart rate following increases in training load.⁷ However, this data was collected
317 during a short pre-season AFL training camp in the heat where environmental and/or training
318 induced changes in plasma volume are more likely responsible than alterations stemmed
319 solely from the previous days training load.⁷ Reductions in heart rate have also been
320 observed in athletes involved in extremely high training loads.⁴⁵ Indeed, HRex during
321 intensified training intensities showed significant reductions in overreached triathletes. Le
322 Meur and colleagues (2013) suggested the cause of this reduction in heart rate to be a hyper-
323 activation of the parasympathetic nervous system via central, cardiac and/or periphery
324 mechanisms.^{46,47} In contrast to Le Meur and colleagues (2013) the results of the current
325 study suggest, although, speculative, an acute stimulation of the sympathetic nervous system
326 thus increasing HRex following a short continued period of training. Indeed, both in
327 recreational marathon runners and world class rowers, a significant increase in sympathetic
328 dominance following a training block in the lead up to competition has been observed.^{48,49}

329 Sensitivity between HRR% and 2-4 day THIR accumulation was trivial and non-significant
330 in the present study. Previous data also failed to find a relationship between daily HRR% and
331 total high-speed running distance over a 17-day competitive period.⁹ In contrast, previous
332 studies have observed responses between both acute and chronic training load and HRR.
333 Borresen and Lambert (2007) found that HRR decreased with an increase in training load and
334 subsequently a tendency for a faster HRR with a decrease in training load. The authors
335 speculate, however, that the reduced HRR with an increase in training load may be explained
336 by the severe increase in training load (TRIMP increased by 55%), potentially inducing
337 overreaching, and hence a parasympathetic predominance as previously discussed⁴⁵. The use
338 of HRex and HRR in healthy athletes to predict changes in performance or fatigue should be
339 treated with caution and interpreted together with other measures of fatigue, such as
340 perceived ratings of wellness.^{14,50} As a consequence, if HR-derived assessments of
341 fatigue/adaptation are to be effective in team sports, a higher volume of assessments may be
342 required as previously discussed. However, undertaking such measures may prove difficult
343 with the large volume of athletes engaged in team sports.¹⁴

344

345

346

347

348

349

350 **Practical Applications**

351

352 Perceived ratings of fatigue show particular promise as simple, non-invasive assessments of
353 fatigue status in elite soccer players during an in-season competitive phase. The present
354 findings also indicate that the sensitivity of morning-measured fatigue variables to changes in
355 training load is generally not improved when compared with training loads beyond the
356 previous days training, therefore, it is likely to be most effective when taken on a daily basis.
357 Future research is needed to determine the acute and longitudinal usefulness of HRex, HRR
358 and vagal related HRV as a monitoring tool in team sports.

359

360 **Conclusion**

361 The sensitivity of morning-measured fatigue variables to changes in training load is not
362 improved when compared with training loads beyond the previous days training. Perceived
363 ratings of fatigue shows the most promise as a simple, non-invasive assessment of fatigue
364 status in elite soccer players in detection of acute load fluctuations during an in-season
365 competitive phase compared to the other markers of fatigue measured.

366

- 367 1. Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. The evolution of physical and
368 technical performance parameters in the English Premier League. *Int. J. Sports Med.*
369 2014;35(13):1095-100. doi:10.1055/s-0034-1375695.
- 370 2. Bradley PS, Archer DT, Hogg B, et al. Tier-specific evolution of match performance
371 characteristics in the English Premier League: it's getting tougher at the top. *J. Sports*
372 *Sci.* 2015;1-8. doi:10.1080/02640414.2015.1082614.
- 373 3. Carling C, Gregson W, McCall A, Moreira A, Wong DP, Bradley PS. Match Running
374 Performance During Fixture Congestion in Elite Soccer: Research Issues and Future
375 Directions. *Sport. Med.* 2015. doi:10.1007/s40279-015-0313-z.
- 376 4. Nimmo MA, Ekblom B. Fatigue and illness in athletes. *J. Sports Sci.* 2007;25 Suppl
377 1:S93-102. doi:10.1080/02640410701607379.
- 378 5. Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the
379 overtraining syndrome: Joint consensus statement of the european college of sport
380 science and the American College of Sports Medicine. *Med. Sci. Sports Exerc.*
381 2013;45(1):186-205. doi:10.1249/MSS.0b013e318279a10a.
- 382 6. Halson SL. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Med.*
383 2014;44 Suppl 2:S139-47. doi:10.1007/s40279-014-0253-z.
- 384 7. Buchheit M, Racinais S, Bilsborough JC, et al. Monitoring fitness, fatigue and running
385 performance during a pre-season training camp in elite football players. *J. Sci. Med.*
386 *Sport* 2013;16(6):550-555. doi:10.1016/j.jsams.2012.12.003.
- 387 8. Gastin PB, Meyer D, Robinson D. Perceptions of wellness to monitor adaptive
388 responses to training and competition in elite Australian football. *J. Strength Cond.*
389 *Res.* 2013;27(9):2518-26. doi:10.1519/JSC.0b013e31827fd600.
- 390 9. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. Monitoring
391 Fatigue During the In-Season Competitive Phase in Elite Soccer Players. *Int. J. Sports*
392 *Physiol. Perform.* 2015. doi:10.1123/ijsp.2015-0004.
- 393 10. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. The
394 Tracking of Morning Fatigue Status Across In-Season Training Weeks in Elite Soccer
395 Players. *Int. J. Sports Physiol. Perform.* 2016. doi:10.1123/ijsp.2015-0490.
- 396 11. Pyne DB, Mujika I, Reilly T. Peaking for optimal performance: Research limitations
397 and future directions. *J. Sports Sci.* 2009;27(3):195-202.
398 doi:10.1080/02640410802509136.
- 399 12. Ispirlidis I, Fatouros IG, Jamurtas AZ, et al. Time-course of changes in inflammatory
400 and performance responses following a soccer game. *Clin. J. Sport Med.*
401 2008;18(5):423-31. doi:10.1097/JSM.0b013e3181818e0b.
- 402 13. Fatouros IG, Chatzinikolaou A, Douroudos II, et al. Time-course of changes in
403 oxidative stress and antioxidant status responses following a soccer game. *J. Strength*
404 *Cond. Res.* 2010;24(12):3278-86. doi:10.1519/JSC.0b013e3181b60444.
- 405 14. Buchheit M. Monitoring training status with HR measures: Do all roads lead to Rome?
406 *Front. Physiol.* 2014;5 FEB. doi:10.3389/fphys.2014.00073.

- 407 15. Borresen J, Lambert MI. Changes in heart rate recovery in response to acute changes
408 in training load. *Eur. J. Appl. Physiol.* 2007;101(4):503-11. doi:10.1007/s00421-007-
409 0516-6.
- 410 16. Lamberts RP, Swart J, Capostagno B, Noakes TD, Lambert MI. Heart rate recovery as
411 a guide to monitor fatigue and predict changes in performance parameters. *Scand. J.*
412 *Med. Sci. Sport.* 2010;20(3):449-457. doi:10.1111/j.1600-0838.2009.00977.x.
- 413 17. Reilly T, Brooks GA. Exercise and the circadian variation in body temperature
414 measures. *Int. J. Sports Med.* 1986;7(6):358-62. doi:10.1055/s-2008-1025792.
- 415 18. Coutts AJ, Duffield R. Validity and reliability of GPS devices for measuring
416 movement demands of team sports. *J. Sci. Med. Sport* 2010;13(1):133-5.
417 doi:10.1016/j.jsams.2008.09.015.
- 418 19. Varley MC, Fairweather IH, Aughey RJ. Validity and reliability of GPS for measuring
419 instantaneous velocity during acceleration, deceleration, and constant motion. *J. Sports*
420 *Sci.* 2012;30(2):121-7. doi:10.1080/02640414.2011.627941.
- 421 20. Waldron M, Worsfold P, Twist C, Lamb K. Concurrent validity and test-retest
422 reliability of a global positioning system (GPS) and timing gates to assess sprint
423 performance variables. *J. Sports Sci.* 2011;29(15):1613-9.
424 doi:10.1080/02640414.2011.608703.
- 425 21. Jennings D, Cormack S, Coutts AJ, Boyd LJ, Aughey RJ. Variability of GPS units for
426 measuring distance in team sport movements. *Int. J. Sports Physiol. Perform.*
427 2010;5(4):565-9. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/21266740>.
428 Accessed November 27, 2014.
- 429 22. Malone JJ, Di Michele R, Morgans R, Burgess D, Morton JP, Drust B. Seasonal
430 Training Load Quantification in Elite English Premier League Soccer Players. *Int. J.*
431 *Sports Physiol. Perform.* 2014. doi:10.1123/ijsspp.2014-0352.
- 432 23. Gaudino P, Iaia FM, Alberti G, Strudwick AJ, Atkinson G, Gregson W. Monitoring
433 training in elite soccer players: systematic bias between running speed and metabolic
434 power data. *Int. J. Sports Med.* 2013;34(11):963-8. doi:10.1055/s-0033-1337943.
- 435 24. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-based
436 training load in soccer. *Med. Sci. Sports Exerc.* 2004;36(6):1042-7. Available at:
437 <http://www.ncbi.nlm.nih.gov/pubmed/15179175>. Accessed December 21, 2014.
- 438 25. Buchheit M, Millet GP, Parisy A, Pourchez S, Laursen PB, Ahmaidi S. Supramaximal
439 training and postexercise parasympathetic reactivation in adolescents. *Med. Sci. Sports*
440 *Exerc.* 2008;40:362-371. doi:10.1249/mss.0b013e31815aa2ee.
- 441 26. Bland JM, Altman DG. Statistical methods for assessing agreement between two
442 methods of clinical measurement. *Lancet* 1986;1(8476):307-10. Available at:
443 <http://www.ncbi.nlm.nih.gov/pubmed/2868172>. Accessed July 9, 2014.
- 444 27. Whittingham MJ, Stephens PA, Bradbury RB, Freckleton RP. Why do we still use
445 stepwise modelling in ecology and behaviour? *J. Anim. Ecol.* 2006;75(5):1182-9.
446 doi:10.1111/j.1365-2656.2006.01141.x.
- 447 28. Flom P and Cassell D. Stopping stepwise: Why stepwise and similar selection methods

- 448 are bad, and what you should use. In: NESUG Stats and Data Analysis 2007. Available
449 at: <http://www.lexjansen.com/pnwsug/2008/DavidCassell-StoppingStepwise.pdf>.
- 450 29. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med.*
451 2000;30(1):1-15.
- 452 30. Hooper SL, Mackinnon LT, Howard A, Gordon RD, Bachmann AW. Markers for
453 monitoring overtraining and recovery. *Med. Sci. Sports Exerc.* 1995;27(1):106-12.
454 Available at: <http://www.ncbi.nlm.nih.gov/pubmed/7898325>. Accessed November 27,
455 2014.
- 456 31. Anderson L, Orme P, Di Michele R, et al. Quantification of training load during one-,
457 two- and three-game week schedules in professional soccer players from the English
458 Premier League: implications for carbohydrate periodisation. *J. Sports Sci.*
459 2016;34(13):1250-9. doi:10.1080/02640414.2015.1106574.
- 460 32. Anderson L, Orme P, Di Michele R, et al. Quantification of Seasonal Long Physical
461 Load in Soccer Players With Different Starting Status From the English Premier
462 League: Implications for Maintaining Squad Physical Fitness. *Int. J. Sports Physiol.*
463 *Perform.* 2016. doi:10.1123/ijsp.2015-0672.
- 464 33. Magalhães J, Rebelo A, Oliveira E, Silva JR, Marques F, Ascensão A. Impact of
465 Loughborough Intermittent Shuttle Test versus soccer match on physiological,
466 biochemical and neuromuscular parameters. *Eur. J. Appl. Physiol.* 2010;108(1):39-48.
467 doi:10.1007/s00421-009-1161-z.
- 468 34. Lastella M, Roach GD, Halson SL, Martin DT, West NP, Sargent C. Sleep/wake
469 behaviour of endurance cyclists before and during competition. *J. Sports Sci.*
470 2015;33(3):293-9. doi:10.1080/02640414.2014.942690.
- 471 35. Silva JR, Rebelo A, Marques F, et al. Biochemical impact of soccer: an analysis of
472 hormonal, muscle damage, and redox markers during the season. *Appl. Physiol. Nutr.*
473 *Metab.* 2014;39(4):432-8. doi:10.1139/apnm-2013-0180.
- 474 36. Cormack SJ, Newton RU, McGuigan MR. Neuromuscular and endocrine responses of
475 elite players to an Australian rules football match. *Int. J. Sports Physiol. Perform.*
476 2008;3(3):359-74. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/19211947>.
477 Accessed November 27, 2014.
- 478 37. Malone JJ, Murtagh C, Morgans R, Burgess D, Morton JP, Drust B. Countermovement
479 Jump Performance is Not Affected during an In-Season Training Microcycle in Elite
480 Youth Soccer Players. *J. Strength Cond. Res.* 2014.
481 doi:10.1519/JSC.0000000000000701.
- 482 38. Gathercole R, Sporer B, Stellingwerff T, Sleivert G. Alternative countermovement-
483 jump analysis to quantify acute neuromuscular fatigue. *Int. J. Sports Physiol. Perform.*
484 2015;10(1):84-92. doi:10.1123/ijsp.2013-0413.
- 485 39. Cormack SJ, Newton RU, McGuigan MR, Cormie P. Neuromuscular and endocrine
486 responses of elite players during an Australian rules football season. *Int. J. Sports*
487 *Physiol. Perform.* 2008;3(4):439-53. Available at:
488 <http://www.ncbi.nlm.nih.gov/pubmed/19223670>. Accessed November 27, 2014.

- 489 40. Al Haddad H, Laursen PB, Chollet D, Ahmaidi S, Buchheit M. Reliability of resting
490 and postexercise heart rate measures. *Int. J. Sports Med.* 2011;32(8):598-605.
- 491 41. Esco MR, Flatt AA. Ultra-short-term heart rate variability indexes at rest and post-
492 exercise in athletes: evaluating the agreement with accepted recommendations. *J.*
493 *Sports Sci. Med.* 2014;13(3):535-41. Available at:
494 [http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4126289&tool=pmcentrez](http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4126289&tool=pmcentrez&rendertype=abstract)
495 [&rendertype=abstract](http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4126289&tool=pmcentrez&rendertype=abstract). Accessed December 22, 2014.
- 496 42. Plews DJ, Laursen PB, Kilding AE, Buchheit M. Heart rate variability in elite
497 triathletes, is variation in variability the key to effective training A case comparison.
498 *Eur. J. Appl. Physiol.* 2012;112(11):3729-3741. doi:10.1007/s00421-012-2354-4.
- 499 43. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and
500 heart rate variability in elite endurance athletes: Opening the door to effective
501 monitoring. *Sport. Med.* 2013;43(9):773-781. doi:10.1007/s40279-013-0071-8.
- 502 44. Buchheit M. Sensitivity of Monthly Heart Rate and Psychometric Measures for
503 Monitoring Physical Performance in Highly Trained Young Handball Players. *Int. J.*
504 *Sports Med.* 2014. doi:10.1055/s-0034-1385882.
- 505 45. Le Meur Y, Louis J, Aubry A, et al. Maximal exercise limitation in functionally
506 overreached triathletes: role of cardiac adrenergic stimulation. *J. Appl. Physiol.*
507 2014;117(3):214-22. doi:10.1152/jappphysiol.00191.2014.
- 508 46. Le Meur Y, Pichon A, Schaal K, et al. Evidence of Parasympathetic Hyperactivity in
509 Functionally Overreached Athletes. *Med. Sci. Sports Exerc.* 2013.
510 doi:10.1097/MSS.0b013e3182980125.
- 511 47. Le Meur Y, Hausswirth C, Natta F, Couturier A, Bignet F, Vidal PP. A
512 multidisciplinary approach to overreaching detection in endurance trained athletes. *J.*
513 *Appl. Physiol.* 2013;114(3):411-20. doi:10.1152/jappphysiol.01254.2012.
- 514 48. Manzi V, Castagna C, Padua E, et al. Dose-response relationship of autonomic nervous
515 system responses to individualized training impulse in marathon runners. *Am. J.*
516 *Physiol. Heart Circ. Physiol.* 2009;296(6):H1733-40.
517 doi:10.1152/ajpheart.00054.2009.
- 518 49. Iellamo F, Pigozzi F, Spataro A, Lucini D, Pagani M. T-wave and heart rate variability
519 changes to assess training in world-class athletes. *Med. Sci. Sports Exerc.*
520 2004;36(8):1342-6. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/15292742>.
521 Accessed September 29, 2015.
- 522 50. Buchheit M, Simpson MB, Al Haddad H, Bourdon PC, Mendez-Villanueva a.
523 Monitoring changes in physical performance with heart rate measures in young soccer
524 players. *Eur. J. Appl. Physiol.* 2012;112(2):711-723. doi:10.1007/s00421-011-2014-0.
- 525

526 Table 1: Partial correlations (95% CI), least squares regression slope (B) and significance for
 527 the relationship between morning-measured perceived fatigue and total high-speed running
 528 distance over the previous 2, 3 and 4-days.

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
2-day	-0.31 (-0.51 to -0.78)	Small	149.167	p=0.01
3-day	-0.42 (-0.61 to -0.18)	Moderate	166.509	p<0.001
4-day	-0.28 (-0.52 to -0.01)	Small	108.53	p=0.03

529

530 Table 2: Partial correlations (95% CI), least squares regression slope (B) and significance for
 531 the relationship between morning-measured perceived sleep quality and total high-speed
 532 running distance over the previous 2, 3 and 4-days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
2-day	-0.03 (-0.27 to 0.21)	Trivial	-10.633	p=0.83
3-day	-0.1 (-0.35 to 0.16)	Trivial	-9.869	p=0.81
4-day	0.04 (-0.27 to 0.28)	Trivial	15.774	p=0.75

533

534 Table 3: Partial correlations (95% CI), least squares regression slope (B) and significance for
 535 the relationship between morning-measured perceived muscle soreness and total high-speed
 536 running distance over the previous 2, 3 and 4-days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
2-day	-0.19 (-0.41 to 0.05)	Trivial/Small	-58.443	p=0.12
3-day	-0.16 (-0.40 to 0.10)	Trivial	-36.258	p=0.23
4-day	-0.13 (-0.4 to 0.15)	Trivial	-28.05	p=0.37

537

538

539 Table 4: Partial correlations (95% CI), least squares regression slope (B) and significance for
 540 the relationship between morning-measured countermovement jump performance and total
 541 high-speed running distance) over the previous 2, 3 and 4 days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
2-day	0.13 (-0.11 to 0.36)	Trivial	24.944	p= 0.29
3-day	0.21 (-0.05 to 0.42)	Small	31.478	p=0.11
4-day	0.23 (-0.05 to 0.48)	Small	34.02	p=0.10

542

543

544 Table 5: Partial correlations (95% CI), least squares regression slope (B) and significance for
 545 the relationship between morning-measured sub-maximal heart rate and total high-speed
 546 running distance over the previous 2, 3 and 4 days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
2-day	0.18 (-0.06 to 0.40)	Trivial	5.17	p=0.10
3-day	0.21 (-0.05 to 0.44)	Small	4.863	p=0.07
4-day	0.28 (0.05 to 0.52)	Small	5.948	p=0.02

547

548 Table 6: Partial correlations (95% CI), least squares regression slope (B) and significance for
 549 the relationship between morning-measured Ln rMSSD (HRV) and total high-speed running
 550 distance over the previous 2, 3 and 4-days.

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
2-day	<-0.01 (-0.25 to 0.29)	Trivial	-1.31	p= 0.99
3-day	<0.01 (-0.27 to 0.25)	Trivial	9.426	p=0.91
4-day	-0.15 (-0.41 to 0.13)	Trivial	-95.337	p=0.279

551

552

553 Table 7: Partial correlations (95% CI), least squares regression slope (B) and significance for
554 the relationship between morning-measured heart rate recovery (HRR%) and total high-speed
555 running distance over the previous 2, 3 and 4-days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
2-day	<0.1 (-0.14 to 0.33)	Trivial	0.178	p=0.97
3-day	<0.1 (-0.16 to 0.35)	Trivial	1.138	p=0.76
4-day	-0.03 (-0.23 to 0.32)	Trivial	-1.584	p=0.68

556