

1 **Monitoring fatigue status in elite team sport athletes: Implications for practice**

2

3 *Brief Review*

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21 **Abstract**

22

23 The increase in competition demands in elite team sports over recent years has
24 prompted much attention from researchers and practitioners into the monitoring of
25 adaptation and fatigue in athletes. Monitoring of fatigue and gaining an understanding
26 of athlete status may also provide insights and beneficial information pertaining to
27 player availability, injury and illness risk. Traditional methods used to quantify
28 recovery and fatigue in team sports such as maximal physical performance
29 assessments may not be feasible in order to detect variations in fatigue status
30 throughout competitive periods. The implementation of more quick, simple and non-
31 exhaustive tests such as athlete self-report measures (ASRM), autonomic nervous
32 system (ANS) response via heart rate derived indices and to a lesser extent jump
33 protocols may serve as promising tools to quantify and establish fatigue status in elite
34 team sport athletes. The robust rationalization and precise detection of a meaningful
35 fluctuation in these measures are of paramount importance for practitioners working
36 alongside athletes and coaches on a daily basis. There are various methods for
37 arriving at a minimal clinically important difference (MCID), but these have been
38 rarely adopted by sports scientists and practitioners. The implementation of
39 appropriate, reliable and sensitive measures of fatigue can provide important
40 information to key stakeholders within team sport environments. Future research is
41 required to investigate the sensitivity of these tools to fundamental indicators such as
42 performance, injury and illness.

43

44

45 **Introduction**

46

47 Elite team sport athletes, particularly those in the professional football codes, are
48 exposed to high competition loads, particularly in recent years. These high loads
49 reflect a number of factors, including an increased frequency of domestic
50 competitions, particularly for higher-level athletes, as well as a higher intensity of
51 competition due to enhanced player preparation strategies.¹ Higher loads may also
52 result from the increased demands of international competition during both the
53 domestic season and the off-season period.

54

55 An increased availability of athletes for selection, as a result of a reduction in injuries,
56 substantially increases a team's chance of success.² Therefore, injury prevention
57 strategies are fundamental to the work of the athlete's support team. Routine
58 modifications in training load (frequency, duration, intensity) occur during the
59 training cycle and these subsequently increase or decrease fatigue. Management of
60 fatigue is important in mediating adaption to training and ensuring the athlete is
61 prepared for competition,³ as well as for reducing the athletes susceptibility to non-
62 functional overreaching, injury and illness.⁴

63

64 The importance of managing athlete fatigue has led to an increase in interest in
65 monitoring athlete loads, particularly in terms of the measures which may offer
66 insights into whether the athlete is adapting positively or negatively to the collective
67 stresses of training and competition. In the present review, we will consider
68 published research concerned with the monitoring of fatigue status in team sport
69 athletes. Information derived from other sports will be examined where evidence in
70 team sport settings is not available. While there are studies in which various proposed

71 moderators and mediators have been found to be statistically significantly associated
72 with fatigue status, in our paper we also highlight the various measurement issues and
73 practical considerations which should be considered by those responsible for the
74 development and implementation of player monitoring systems in the field. We focus,
75 especially, on the neglected topic of all the different approaches to selecting a
76 minimal worthwhile change in fatigue status. It is hoped that our overview will
77 provide the basis for the development of a framework for evaluating fatigue status in
78 team sports and provide some guidance for future investigators.

79
80 It is not our intention to comprehensively describe the available information on the
81 etiology of fatigue or the scientific basis of common recovery intervention practices.

82 Such information can be found in several excellent recent reviews.^{5,6} For the purpose
83 of this review, and to align with previous reviews in this area, fatigue will be defined
84 as “an inability to complete a task that was once achievable within a recent time
85 frame”^{3,7}

86 87 **Methods for Monitoring Fatigue**

88
89 Training load reflects the internal and external loads imposed upon the athlete.⁸
90 External load relates to work completed by the athlete independent of his or her
91 internal characteristics and is important for understanding the capabilities and
92 capacities of the athlete.⁷ The internal load, or the relative physiological strain
93 resulting from the external training factors, is also crucial to determining both the
94 stress imposed and subsequent adaptation to training.⁹ A combination of both the
95 external and internal load is therefore important for training since the uncoupling or
96 divergence of external and internal loads may differentiate between a non-fatigued
97 and a fatigued athlete.^{3,7} This approach is particularly relevant in “closed loop” sports
98 like cycling where the performance outcome is time, and the power produced by the
99 rider is known to have a relatively precise association with the performance time.
100 Under such conditions, the internal load needed to sustain a certain external load
101 (power output) can provide important information regarding the athletes fatigue
102 status.⁷

103 In contrast to “closed loop” sports, the ability to relate external and internal loads in
104 “open loop” sports like team sports is difficult due to the inherent variability in
105 physical performance during sport-specific training drills¹⁰ and match-play.¹¹ As a
106 consequence, attempts to monitoring the fatigue status of team sport athletes have
107 largely focused on the assessment of internal and external load measures under resting
108 conditions and/or during submaximal exercise assessments on the morning prior to
109 training. Within the confines of this approach, a valid indicator of fatigue in team
110 sports should be sensitive to training load and their response to acute exercise should
111 be distinguishable from chronic changes in adaptation.¹² Prospective tools should
112 also be non-invasive, quick and easy to administer and limit any additional loading on
113 the athlete. This is particularly important in football codes, where competition occurs
114 on a weekly basis and in some instances on 2-3 occasions a week meaning that
115 players are required to peak with limited recovery between matches.

116 *Athlete self-report measures*

117

118 Recent surveys on fatigue monitoring in high performance sport demonstrate that athlete
119 self-report measures (ASRM) are used extensively for assessing the overall well-being of
120 team sport athletes.¹³ A plethora of ASRM currently exist including the POMS,^{14,15}
121 DALDA,¹⁶ TQR¹⁷ and REST-Q^{18,19} which have been extensively documented in the
122 literature. However, many of these are often extensive and time-consuming to complete
123 preventing their use on a daily basis with large numbers of team athletes. Many team
124 sports therefore often adopt shorter, customised questionnaires which can be
125 administered on daily basis.¹³ A recent review highlighted that ASRM demonstrate
126 greater sensitivity to acute and chronic training loads compared to commonly used
127 objective measures.²⁰ In team sports, for example contemporary Australian Football
128 League (AFL) and English Premier League (EPL) research has shown custom
129 psychometric scales to be sensitive to daily, within-weekly and seasonal changes in
130 training load.²¹⁻²³ Indeed, daily ASRM (fatigue, sleep quality, stress, mood and muscle
131 soreness) were significantly correlated with daily training load in a pre-season camp and
132 competitive period in AFL and EPL players respectively.^{22,24} Similarly, ASRM were
133 sensitive to changes in training load during typical weeks in AFL and EPL players across
134 the course of the season.^{21,23,25} Further importance of ASRM and relationship with
135 injury/illness has been observed in Rugby League, in this study fluctuations in ASRM
136 between macrocycles were shown to provide useful insights into possible illness risk in
137 players.²⁶ Further work is required to examine the relationships between ASRM and
138 injury/illness risk in team sport athletes.

139

140 *Autonomic Nervous System (ANS)*

141

142 The ANS is interlinked with many other physiological systems,²⁷ significant attention
143 in the literature has therefore centered upon the use of indicators of ANS functioning
144 for determining an athletes overall adaptation/fatigue status. To date this has largely
145 stemmed from studies examining the sensitivity of heart rate (HR) derived indices
146 including resting heart rate (RHR), exercising heart rate (HREx)²⁸, heart rate
147 variability (HRV)^{27,28} and heart rate recovery (HRR)^{28,29} to fluctuations in training
148 and competition load.

149

150 *Submaximal heart rate (HREx)* Decreases in HR during standardised exercise bouts
151 have traditionally been associated with increases in aerobic fitness. However, the
152 majority of data available has reported inconsistent results in non-team sport athletes.
153 Heart rate during intensified training and during varying intensities showed
154 significant reductions in overreached triathletes. Le Meur and colleagues suggested a
155 hyper-activation of the parasympathetic nervous system via central, cardiac and/or
156 periphery mechanisms.^{30,31,28} Recent observations in AFL have also reported
157 reductions in heart rate in response to training during pre-season, although, the
158 authors concluded this was more possibly due to the effects of training/environmental
159 induced changes in plasma volume than acute changes in fitness or fatigue. Contrary
160 to these reports, exercising heart rate in EPL players failed to fluctuate in response to
161 within week changes in training and match load over the course of a season.²⁵ The
162 use of HREx in healthy athletes to predict negative effects in performance or fatigue
163 should be treated with caution and interpreted together with other potential measures
164 of fatigue such as ASRM.^{28,32}

165

166 *Heart rate variability (HRV)* Vagal-related time domain parameters of HRV have
167 recently received greater attention than more traditional spectral analyses due to their
168 superior reliability and assessment capture over short periods of time.^{33,34} Sensitivity
169 to changes in training load and performance has mainly been observed in non-team
170 sports.^{27,35} Generally, HRV is reduced (sympathetic dominance) in the immediate
171 days following intense exercise,³⁶ however, results from endurance sports have
172 shown inconsistent results.³⁷ Little evidence currently exists with regards to its
173 sensitivity to fluctuations in training and competition load in team sports. In AFL
174 players undertaking pre-season training in the heat, a vagal-related HRV parameter
175 (SD1) was largely and statistically significantly correlated ($r \sim -0.5$) to daily RPE-TL.
176²² However, these unexpected changes in parasympathetic activity may have been
177 partly mediated through thermoregulatory mechanisms associated with alterations in
178 plasma volume.^{22,36} In elite soccer, HRV (Ln rMSSD) appeared to decrease ($r = -0.2$),
179 albeit, transiently in response to high-speed running distance.²⁴ Contrastingly, in the
180 same population, HRV did not change across a standard in-season training week.²⁵
181 Interestingly, data derived from endurance sports have suggested that the sensitivity
182 of HRV to training and competition may be improved when data is averaged over a
183 week or using 7-day rolling averages compared to the use of single data points due to
184 the high day-to-day variation in these indices. However, undertaking such measures
185 may prove difficult with the large volume of athletes engaged in team sports.³⁸ Future
186 research is needed to determine whether such approaches enhance the suitability of
187 these measures for use in team sport populations.

188

189 *Heart rate recovery (HRR)* Post exercise HRR reflects general haemodynamic
190 adjustments in relation to body position, blood pressure regulation and metaboreflex
191 activity, which partly drives sympathetic withdrawal and para-sympathetic
192 reactivation.³⁹ Recent findings in endurance sports have shown that HRR may serve
193 as a sensitive marker of acute training load alteration,^{27,29} although this association
194 has yet to be seen in team sports.³² HRR did not fluctuate in response to daily and
195 within week training load variability in EPL players.^{24,25} Data from physically active
196 men and women have shown a delay in HRR following increases in training load.²⁷
197 More recently, non-functionally overreached elite triathletes showed a faster (8 beats
198 per min) HRR compared to elite triathlete controls following the same training
199 program.⁴⁰ It appears that HRR is responsive to both acute and chronic changes in
200 training load, however, the exact direction of this change and whether HRR can detect
201 fatigue status remains unclear and should be interpreted alongside training status and
202 with caution.⁴¹

203

204 *Physical Performance*

205

206 A variety of maximal performance assessments (sprints, repeated sprints, jumps and
207 maximal voluntary contractions) have been used in attempt to quantify the rate of
208 recovery of performance in the hours and days following training and competition in
209 team sports.⁴²⁻⁴⁶ Whilst these types of assessment provide important information, the
210 application of physical performance tests which are exhaustive in nature and time
211 consuming to deliver means they are often unsuitable for use in team sport
212 environments.^{46,47} Quick, efficient and without additional load represent the only feasible
213 maximal performance assessments applicable for team sport players.

214

215 *Neuromuscular function*

216 Various jump protocols including squat jump (SJ) and countermovement jump (CMJ)
217 have been adopted to examine the recovery of neuromuscular function following
218 competition with significant decreases for up to 72-hours routinely reported.⁴²⁻⁴⁶
219 However, less attention has focused on examining their sensitivity to changes in
220 training load. CMJ was not sensitive as a measure of neuromuscular status in EPL
221 players when analysed alongside daily fluctuations in training load, furthermore, data
222 derived from elite Rugby Sevens and adolescent soccer players revealed no change in
223 countermovement jump height or correlation to training load during a taper and across
224 a training period respectively.⁴⁸⁻⁵⁰ The use of jump height per se as a global indicator
225 of neuromuscular function may lack the sensitivity to detect changes in training load
226 in previous studies. Moreover, CMJ height alone may mask alternative neuromuscular
227 measures and their sensitivity to alterations in load. Reductions in 18 different
228 neuromuscular variables were found following a high-intensity fatiguing protocol in
229 college-level team sport athletes.⁵¹ Neuromuscular parameters (eccentric, concentric,
230 and total duration, time to peak force/power, flight time:contraction time ratio)
231 derived from CMJ were deemed suitable for neuromuscular fatigue detection.⁵¹ In
232 AFL, variations in force-time parameters (flight time:contraction time ratio) were
233 observed over the course of a season, indicating sensitivity to increases in load over
234 time.⁵² Future research is required to investigate whether alternative measures
235 derived from CMJ are sensitive to changes in training load in elite team sport athletes.

236 *Joint range of motion (JROM)/ Flexibility*

237
238 Simple clinical assessments of JROM have been typically performed on a one-off
239 basis as part of a pre-season screening battery in elite team sport.⁵³ However, there is
240 a lack of data reporting JROM responses to training and match load. Indeed, the
241 assessment of JROM more regularly during competitive periods may provide greater
242 information pertaining to structural fatigue and potential injury risk compared to a
243 single pre-season assessment. In elite soccer players, knee range of motion was
244 reduced until 48-hours post-match.⁴³ Similarly, Mohr and colleagues (2015) found
245 knee joint range of motion declined 7% at both 24- and 48-hours post-match.⁵⁴
246 Moreover, structural assessments quantifying hip/groin extensibility have shown good
247 reliability and validity following match-play in youth soccer players.⁵⁵ Indeed, a
248 reduction of more than 12.5% in adductor (bent knee fall out test) range 14-hours
249 post-match was deemed a meaningful change in youth soccer players. The simple and
250 quick nature of JROM assessments evaluating key anatomical regions may provide a
251 greater understanding of structural status and potential injury risk. Future research is
252 required, to examine the time-course of recovery for JROM measures post-match and
253 their sensitivity to changes in load in team sport athletes.

254

255

256 *Biochemical/Hormonal/Immunological*

257

258 A large amount of research has examined a range of biochemical, hormonal and
259 immunological responses to team sport competition.^{46,47} It is beyond the scope of this
260 article to review the collective literature surrounding the responses of such measures in
261 team sports, however, no definitive marker has been derived for examining the fatigue
262 status of athletes. Furthermore, the associated costs and in some instances time

263 consuming nature of their analyses, often means many of these measures are impractical
264 for use in the team sport environment.

265

266 A variety of markers have been used in an attempt to examine potential levels of muscle
267 damage in athletes. Creatine kinase (CK) increases immediately post-match in soccer⁴³
268 and rugby⁵⁶ and peaks between 24-48-hours with a return to baseline values observed
269 from 48-120-hours.^{42-46,57} Although widely used, questions remain regarding the exact
270 mechanism of activity following exercise and its relationship with muscle function
271 recovery.^{46,58} IL-6 is produced in larger amounts than any other cytokine prompting its
272 use as a global measure of inflammation.⁵⁹ IL-6 peaks immediately following the
273 cessation exercise and then rapidly returns to baseline values after 24-hours.^{42,43,54} C-
274 reactive protein (CRP) and uric acid have been found to be a more sensitive marker of
275 inflammation following soccer match-play.^{43,45,54} Indeed, increases of up ~50%, 48-
276 hours post-match has been observed in elite soccer players.⁴⁵ Furthermore in a similar
277 study in elite soccer players, uric acid peaked 72-hours following a match.⁴³ Adrenal
278 hormones cortisol and testosterone have been shown to increase up to 48-hours following
279 competition and up to 50% post-competition in team sports respectively.⁵⁴ Salivary
280 immunoglobulin A (S-IgA) has become a popular means to assess mucosal immunity in
281 athletes following via the use of real time lateral flow devices. In EPL players S-IgA
282 showed reductions during a taper phase and a period of international competition,^{60,61}
283 Little longitudinal data particularly around competition and training phases currently
284 exists in team sports. The impractical nature and cost of individual samples may explain
285 the limited data assessing biochemical, hormonal and immunological measures over
286 extended training and competition periods in team sports.

287

288 **Measurement Considerations**

289

290 In a recent BJSM editorial, McCall et al. (2016) described the concept of “working
291 fast - working slow”, whereby the researcher undertakes robust and sometimes long-
292 term studies in order for the practitioner to make informed sometimes “on the spot”
293 decisions in conjunction with players and coaches.^{62,63} This “working fast – working
294 slow” concept is a relevant measurement issue because practitioners need to ensure
295 that a given measurement of fatigue or performance can be interpreted quickly and
296 accurately against the backdrop of random within-subjects variability, which may be
297 quantified by the researcher in a well-designed reliability study. Any measurement of
298 fatigue also needs to be interpreted with knowledge about how valid the measurement
299 tool is to the ultimate outcomes of player performance, illness and/or injury. This
300 knowledge is derived from well-designed and robust validity studies⁶⁴ as well as
301 prognostic-type studies in which fatigue is the predictor and injury rate, for example,
302 is the outcome.

303

304 Measurement decisions should definitely not be based solely on whether a particular
305 reliability or validity statistic, e.g. a correlation coefficient, is “statistically
306 significant” or not.⁶⁴ Similarly, published general qualitative thresholds of
307 “excellent”, “good” or “moderate” measurement statistics may not always be fully
308 informative for decision making purposes. For example, it has been thought in the
309 past that a measurement tool can be deemed sufficiently reliable if the test-retest
310 coefficient of variation (CV) is <10% and/or if a test-retest correlation is >0.8, but the
311 rationale for these general thresholds has not been very clearly described in the past.

312 ⁶⁴ The ideal process is for a given measurement of fatigue status to be interpreted

313 relative to both random within-subjects variability (thereby deriving the “minimal
314 detectable change”) as well as the minimum value that has been deemed to be
315 clinically or practically important; the “MCID”.⁶⁵⁻⁶⁷ It is important to consider that
316 the minimal detectable change might not be the same as the MCID. A minimum
317 detectable change is the smallest true change that has a reasonable probability of
318 being statistically significant. A properly-powered study should mean that the
319 minimum detectable effect is achieved, but this effect size might still not be clinically
320 or practically important.

321
322 Once the MCID has been selected and reliability/validity information is collected on a
323 relevant sample, this process is essentially probabilistic in nature, whereby one can
324 estimate the chances that a given measurement exceeds the MCID. While useful
325 spreadsheets exist to undertake this process⁶⁸ the magnitude of the selected MCID is
326 critical for the process of monitoring fatigue to be useful and informative in the field.

327
328 The quantification of an MCID is also imperative for accurate *a priori* sample size
329 estimations in applied research.⁶⁹ This sample size estimation is important for ethical
330 and economic reasons. It may be unethical and wasteful of time and money for a
331 researcher to collect data, possibly with invasive methods, if the sample size is too
332 small to detect the MCID. A large sample size may also be unethical if a treatment
333 effect could have been quantified with adequate precision using a much smaller
334 sample.

335
336 An MCID might be relatively straightforward to select in “closed loop” sports like
337 individual track cycling where the performance outcome to anchor to is clearly time,
338 and objective indicators like the power produced by the rider are known to have a
339 relatively precise association with this performance time. Changes in performance
340 time (and associated indicators) may also be stable enough for the practitioner to link
341 directly to meaningful changes in athlete ranking.⁶⁸ Nevertheless, the selection of an
342 MCID for team sport performance is more difficult due to the multi-component nature
343 of these sports and the relatively high within-subject variability in physical
344 performance between successive soccer-specific training drills¹⁰ and match-play.^{11,70}
345 Furthermore, the use of highly demanding maximal performance tests, as possible
346 closer surrogates of match performance, is difficult in team sports due to the limited
347 recovery time between frequent competitions and matches. The magnitude of an
348 MCID may also depend on whether it is considered from the perspective of the
349 athlete, the coach or even the club’s financiers/owners. For example, an MCID for a
350 player may be the change in fatigue that leads to a perceived increase in match
351 performance. The coach may be more interested in the MCID that confers the greatest
352 probability of longer-term availability and the financiers may be more interested in the
353 MCID that confers both the former consequences as well as adding to the transfer
354 value of the player. Obviously, all of these anchors are associated with each other, yet
355 it is uncommon for these different perspectives to be considered together, using a
356 Delphi method for example.

357
358 The approaches for selection of an MCID have mostly been considered in detail from
359 a clinical trial perspective.^{66,67,71} Researchers and practitioners could gather
360 information about the MCID using expert/end-user opinion, evidence synthesis and a
361 pilot study, ideally by triangulating across these different approaches. Nevertheless,

362 although a certain difference derived from an evidence synthesis or pilot study might
363 be a realistic target, it might not necessary be clinically/practically important itself.

364

365

366 There are two main types of approaches for quantifying an MCID; anchor and
367 distributional (statistical). In the “anchor” approach, the measurement (or change in
368 measurement) is anchored to an associated change in another external measure of
369 change; the anchor variable. For example, a change in fatigue status could be
370 anchored to changes in illness, soft-tissue injury and/or match performances/rankings.
371 Ideally, the robustness of any relationship between an indicator variable (or exposure)
372 and the anchor should be quantified in prognostic-longitudinal type research.⁷² In
373 these types of studies, it is imperative to employ the most appropriate analysis
374 approaches, as highlighted recently by Finch and Marshall.⁷³ These authors
375 recommended that epidemiological studies into sports injuries should use the
376 “Subsequent Injury Categorisation model” to make full use of all the longitudinal data
377 that are collected.

378

379 Distributional approaches for specifying an MCID can be based on the standard error
380 of measurement (typical error) and/or the between-subjects SD for the measured
381 variable (e.g. $>0.2SDs$). In the former approach, a measurement (or change in
382 measurement) is compared with an MCID that is larger than the random and
383 unavoidable within-subjects variability (standard error of mean). Additional decisions
384 in this approach are how much larger than random variability should the MCID be as
385 well as what level of statistical precision should be selected, although it has been
386 reported that a reasonable MCID approximates to 1SEM⁷⁴

387

388 A related concept to the SEM is the “minimal detectable change”. For example, a
389 change in measurement could be deemed important if it exceeds twice the standard
390 deviation of differences (derived from a reliability study). The standard deviation of
391 differences can be estimated by multiplying the SEM by $\sqrt{2}$. This threshold of $2xSD$
392 of differences is essentially the 95% limits of agreement described by Bland and
393 Altman.^{75,76}

394

395 Health economics may also be factored into the MCID selection process. This would
396 involve defining a threshold value for the cost of a change in performance or a
397 reduction in illness or injury that a coach or team owner is willing to pay. Then data
398 on the differences in costs, effects and harms can be all considered together to arrive
399 at an estimate of relative efficiency. It is common for changes in measurements to be
400 considered on a standardised scale, e.g. as a given fraction of the between-subjects
401 standard deviation. Various thresholds have been proposed for trivial, small, medium
402 and large effects.^{77,78} For injury applications, binary or survival (time-to-event)
403 outcome metrics (e.g. an odds, risk or hazard ratio) can be considered in a similar
404 way. Effect size thresholds for risk ratio values depend on the “nominal” event
405 proportion, i.e. that observed in the control group.

406

407

408 **Practical Applications & Future Direction**

409

410 Elite team sport athletes compete on a weekly basis and often 2-3 times per week in the
411 football codes. Whilst adhering to the fundamental measurement requirements outlined in

412 this review, prospective fatigue monitoring tools should also be non-invasive and time
413 efficient due to the large volume of players who may require assessing on any given day.
414 The tools should also minimize any additional loading due to the limited recovery time
415 available to team sport athletes during the competition phase. Recent surveys on current
416 trends of fatigue monitoring in high performance sport, highlight athlete self-report
417 questionnaires as the most frequently adopted tool, particularly customized designs
418 consisting of 4-12 items.¹³ The validity of these tools is also supported by a number of
419 reports highlighting their sensitivity to training and/or match load.^{21,22,25,79,80} However,
420 the efficacy of these tools is dependent upon a number of theoretical (inter-relations
421 between the measure, social environment and outcomes) and practical factors that need to
422 be addressed within the applied sports setting.²⁰

423
424 Research to date has mainly examined the sensitivity of prospective fatigue
425 monitoring tools to previous training and match load. Future work is required to
426 examine the degree to which a fatigue measure or change in fatigue measure promotes
427 subsequent changes in a relevant anchor such as performance, illness and injury. This
428 represents a move towards establishing the MCID for fatigue measures and in doing
429 so align with approaches adopted in clinical practice⁷¹ as outlined earlier in this
430 review. From a performance perspective, establishing pre-training or pre-match
431 MCID for fatigue measures would theoretically offer an indication on the quality of
432 the external output that might be produced.²³ This would provide coaches with the
433 ability to make adjustments to the scheduled training or rotate the players from a
434 match perspective. However, application to match-play is unlikely to be feasible due
435 to the high inherent variability of match-play physical performance in team sports.
436^{11,70} The use of more 'closed loop' sport-specific training drills where players may
437 possibly perform more consistent physical outputs may afford an opportunity to
438 establish pre-training MCID for fatigue measures.

439
440 There is now a growing body of literature highlighting links between increased athlete
441 loading (competition and training loads) and the incidence of soft-tissue injury and to
442 a lesser extent illness in team sports (see Drew et al., 2016 for a review of recent
443 work).⁸¹ Furthermore, internal loading may offer more accurate predictions of injury
444 risk than measures typically used to estimate the external load.⁷ In these studies,
445 internal load was largely estimated by multiplying total training or match session
446 duration with session ratings of perceived exertion.⁸² Future work, is required to
447 examine whether other measures of the internal load/fatigue status of the athlete may
448 further enhance the precision of these estimates. For example, a number of studies
449 have examined the relationship between psychological stress and injury in sports^{83,84}
450 though only few reports have examined these relationships in team sports using
451 athlete self-report assessments commonly used in practice.^{85,86} By examining the role
452 of various prospective measures of fatigue status we may enhance our ability to
453 observe changes in the athletes status, which may predispose them to illness and/or
454 injury. Although, fatigue experienced by team sport athletes is multifactorial in nature
455 and one single measure is insufficient in explaining athlete status. A combination of
456 subjective and objective measures is, therefore, more likely in order to quantify
457 fatigue status in elite team sport athletes.

458
459
460
461

462 **Summary**

463

464 Considering the increase in competition demands in elite team sports over recent
465 years, the quantification of fatigue status has gained popularity amongst researchers
466 and practitioners. Since maximal physical performance assessments (sprints, repeated
467 sprints and maximal voluntary contractions) traditionally used to quantify recovery
468 and fatigue in athletes are unsuitable in team sport environments due to their
469 exhaustive and time-consuming nature, recent literature has demonstrated that quick,
470 simple and non-invasive tools such as ASRM, ANS HR-indices, JROM and jump
471 protocols which have been shown to be sensitive to changes in training load.
472 Practitioners utilising such measures must consider the MCID when interpreting
473 results to identify true sensitivity in athlete fatigue status and in turn, informed
474 decisions alongside key stakeholders in elite team sport environments. This review
475 has outlined the potential measures which may be used as a starting point by
476 practitioners to monitor fatigue status in team sport athletes, however, future work is
477 required to investigate the relationships between these measures of fatigue and global
478 anchors such as performance, injury and illness.

479

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