Fitzpatrick, J., Akenhead, R., Russell, M., Hicks, K., & Hayes, P. (2019). Sensitivity and reproducibility of a fatigue response in elite youth football players. *Science and Medicine in Football*.

Document version
Peer reviewed version

Licence
Unspecified

Fitzpatrick, J., Akenhead, R., Russell, M., Hicks, K., & Hayes, P. (2019). Sensitivity and reproducibility of a fatigue response in elite youth football players. Science and Medicine in Football. X(X)

Sensitivity and reproducibility of a fatigue response in elite youth football players

John F. Fitzpatrick[1, 2], Richard Akenhead[3], Mark Russell[4], Kirsty M. Hicks[1], Philip R. Hayes[1]

[1] Department Sport, Exercise and Rehabilitation, Northumbria University, Newcastle-upon-Tyne, UK.

[2] Sports Science and Medical Department, Newcastle United Football Club, Newcastle-upon-Tyne, UK.

[3] The Football Association, St. George's Park, Burton-upon-Trent, UK.

[4] School of Social and Health Sciences, Leeds Trinity University, UK.

Abstract word count: 198

Manuscript word count: 3481

Number of Tables: 4

Number of Figures: 0

Corresponding Author:

John F. Fitzpatrick

Email: John.Fitzpatrick@nufc.co.uk

Co-author contact details:

Richard Akenhead - Richard.Akenhead@thefa.com

Mark Russell - M.Russell@leedstrinity.ac.uk

Kirsty M. Hicks - Kirsty.Hicks@northumbria.ac.uk

Philip R. Hayes - Phil.Hayes@northumbria.ac.uk

Abstract

This study aimed to establish firstly, the sensitivity of subjective wellness, jump performance and tri-axial accelerometer measures to training-induced fatigue and secondly, the reproducibility of this training-induced fatigue response. In 14 elite youth football players, morning assessments of subjective wellness (fatigue, sleep quality, muscle soreness, stress and mood), jump performance (countermovement jump height [CMJ], squat jump height [SJ] and drop jump contact time [DJ-CT], height [DJ-JH] and reactive strength index [DJ-RSI]) and tri-axial accelerometer data (PlayerLoad^{TM} (PL), the individual movement planes of PL (anterior–posterior [PL_{AP}], mediolateral [PL_{ML}] and vertical [PL_{V}]) and the percentage contribution of each component plane) were collected before (-24 h and immediately prior) and after (+24 h, +48 h) a standardised strenuous training session on two occasions in order to assess the reproducibility of a training-induced fatigue response. Sensitivity was assessed via the signal: noise (S:N) ratio of the changes in fatigue measures +24 h post training and the minimum detectable change for each measure. DJ-RSI, PL_{ML} and %PL_{V} were found to be sensitive measures of training-induced fatigue, which displayed a reproducible response (S:N >1 on both occasions). CMJ, SJ and all subjective wellness measures were not able to detect a reproducible fatigue response.

Keywords: Fatigue; Monitoring; Accelerometer; Soccer

Introduction

Team sport activity has been shown to elicit fatigue commensurate with performance decrements and increased injury risk in youth and senior players (Mohr et al. 2005; Rampinini et al. 2011). In an attempt to make informed decisions about readiness to train and training prescription, applied practitioners seek methods that attempt to quantify the magnitude of fatigue throughout the competitive week (McCall et al. 2014). Many methods exist to detect fatigue in an applied setting; self-report measures, assessments of autonomic nervous system function, physical performance tests and biochemical markers to name a few (Twist and Highton 2013; Halson 2014). However, concerns about the reliability, sensitivity and logistical feasibility may prevent such methods from being used on a regular basis (Akenhead and Nassis 2016).

Surveys on fatigue monitoring in high performance sport demonstrate that subjective wellness monitoring is used extensively for assessing the overall well-being of team sport athletes (Taylor et al. 2012; Akenhead and Nassis 2016). A recent review highlighted that subjective monitoring identified impaired wellness with acute increases in training load, and improved wellness with an acute reduction in training load (Saw et al. 2015). Furthermore, subjective measures responded with superior sensitivity and consistency compared to objective measures, such as endocrine or heart rate measures. Daily subjective wellness has been shown to correlate with daily fluctuations in training load, indicating a possible dose-response relationship (Thorpe et al. 2015; Scott and Lovell 2017). Despite this body of evidence suggesting subjective wellness questionnaires are able to detect a perception of fatigue, the reproducibility of a subjective fatigue response is still an important consideration that has yet to be investigated within the literature.

A number of different jump tests including squat jump (SJ), CMJ and drop jump (DJ) are used as surrogate measures of neuromuscular function following exercise, with reductions in jump performance reported for up to 72 hours (Nédélec et al. 2012; Silva et al. 2018). Brownstein et al. (2017) found decrements in CMJ height and DJ-RSI immediately post match play and at 24 h before recovering at 48 h post. Additionally, they found a substantial relationship between CMJ height and motor point voluntary activation, indicating that central mechanisms of neuromuscular function might be the cause of the decrements in CMJ height. However, the sensitivity of jump tests to changes in training load remain unclear. In football players, CMJ was not sensitive as a measure of physical function when analysed alongside daily fluctuations in training load (Thorpe et al. 2015). It has been suggested that jump height might not be sensitive as an altered "jump strategy" might be utilised to maintain jump height in the presence of fatigue (Gathercole et al. 2015). Other force-time variables such as the flight time: contraction time ratio (Cormack et al. 2008) or reactive strength index (Hamilton 2009) have displayed a sensitivity to changes in training load and therefore may offer a more appropriate measure of neuromuscular function than jump height. Similar to subjective wellness however, no research to date has established if assessment of jump performances can reproducibly detect a fatigue response.

The use of tri-axial accelerometers, such as those integrated into micro-electro-mechanical systems (MEMS), have demonstrated an ability to detect fatigue post exercise (Patterson et al. 2011; Cormack et al. 2013). Fatigue has been shown to result in an altered gait strategy during running (Patterson et al. 2011), which has been associated with reduced sprint and jump performance (Mendez-Villanueva et al. 2008; Gathercole et al. 2015), as well as increased injury risk (De Ste Croix et al. 2015). Further, it has been shown that during a fatigue-inducing repeated sprint protocol, large decrements in accelerometer load, specifically vertical acceleration where observed (Akenhead et al. 2017). The result of an altered running strategy

is determined by a reduction in the vertical acceleration of the centre of mass (CoM) during running (Lee and Farley 1998), which has previously been detected by an integrated accelerometer worn between the scapula (Barrett et al. 2014). Cormack et al., (2013) attributed the reduction in vertical load, in fatigued elite Australian rule football players, to reductions in force absorbing and generating capacity of the leg extensor, which could potentially have implications for injury risk (Barrett et al. 2016).

A multitude of different measures have been used within the literature to try and monitor fatigue on a daily and/or weekly basis, with varying degrees of sensitivity. For a fatigue monitoring measure to be successful, it must show a reproducible dose-response relationship, which is currently lacking within the literature. Therefore the aim of the present study was to firstly, establish the sensitivity of subjective wellness, jump performance and tri-axial accelerometer measures to training-induced fatigue and secondly, the reproducibility of this training-induced fatigue response in elite youth football players.

Materials and Methods

Experimental overview

Twelve youth soccer players (Age: 17.5 ± 0.5 years, Height: 177.0 ± 4.9 cm, Body Mass: 72.4 ± 8.9 kg), competing in the English Under-18 Premier League agreed to participate in the present study. Participants were given full details of the study procedures and provided personal, and when under 18 years of age, parental consent before participation. Institutional ethical approval was gained prior to any study involvement. Prior to inclusion in the study, all participants were deemed fit and free of illness or injury by the club's medical staff.

This study was completed at the start of the in-season period and consisted of eight testing sessions over a two week period. Players completed morning assessments of fatigue, prior to training. Each testing session consisted of morning ratings of subjective wellness, assessments of jump performance and a sub-maximal shuttle run test. Testing was completed before (-24 h, immediately pre) and after (+24h, +48 h) training. Training was standardised over the first two days, with a low training load session on day one and a very high training load session on day two (Table 1). All testing sessions were conducted at the same time of day to minimise possible effects of circadian variation. All players were familiarised with the experimental procedures, which form part of their training and monitoring routinely.

Subjective wellness

A psychometric questionnaire based on previous recommendations was used each day to assess general indicators of player wellness (Hooper and Mackinnon 1995). The questionnaire was composed of five questions, minimum detectable changes (MDC) are presented from unpublished observations within this specific cohort. Questions related to fatigue (MDC 0.47 au), sleep quality (MDC 0.93 au), muscle soreness (MDC 0.95 au), stress (MDC 0.93 au) and mood (MDC 0.95 au) (McLean et al. 2010). Each question was scored on a five-point Likert scale with single point increments (scores of 1–5, with 1 and 5 representing very poor and very good, respectively). The summation of all five scores provided a total wellness score (5-25) (MDC 2.54 au).

Jump performance

A standardised warm up consisting of three minutes light aerobic activity on a cycle ergometer (Keiser, Fresno, CA, USA), followed by dynamic mobility exercises and three sub-maximal practice jumps was conducted prior to each testing session. Players then performed three different tests to assess jump performance; CMJ (MDC 2.47 cm, unpublished observations),

SJ (MDC 2.26 cm) and DJ. The CMJ was executed to a self-selected depth with the hands placed on the hips. Players were instructed to jump as high as possible with no knee or hip flexion during the flight phase, landing in the same position as take-off. The same instructions were given for the SJ however, players were instructed to hold their self-selected depth for a 4 s count, and the amplitude of countermovement before propulsion was visually checked. The DJ was performed from a 30 cm box with hands on hips. Players were instructed to step off the box, rebound off the floor as quickly as possible and jump as high as possible as previously described (Brownstein et al. 2017; Thomas et al. 2017). Each assessment consisted of four attempts at each test, separated by a one minute rest. Jumps were performed in a randomised counterbalanced manner to reduce order effects. All jumps were completed on an optical measurement system (Optojump, Microgate, Italy), the validity of which has been established (Glatthorn et al. 2011). Jump height was recorded for CMJ and SJ, while for DJ, contact time (DJ-CT) (MDC 0.01 s), jump height (DJ-JH) (MDC 2.76 cm) and reactive strength index (DJ-RSI) (MDC 0.16 $m.s^{-1}$) were recorded.

Sub-maximal shuttle run test

A sub-maximal shuttle running test was used to assess players' mechanical loading. All players were fitted with a micro-electro-mechanical systems (MEMS) device (MinimaxX S4, Catapult Sports, Melbourne, Australia) worn between the scapular in a tight-fitting vest to reduce movement artefact. MEMS devices contained a tri-axial piezoelectric linear accelerometer (Kionix: KXP94) sampling at a frequency of 100 Hz. A continuous 20 m shuttle run was performed for a three minute period, at an average speed of 12 $km·h^{-1}$ on an artificial 3G surface. Pacing was controlled using a custom audio track played over a loudspeaker. Data were downloaded using the manufacturer's software (Catapult Sprint, Version 5.1.7) and raw data were exported to Microsoft Excel. The first minute of data was discarded as a stabilisation

period, the subsequent two minutes of the collection period were used for statistical analysis. Combined tri-axial accelerometer data were presented as PlayerLoad™ (PL) (MDC 1.38 au, unpublished observations), which is a modified vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three planes divided by 100 (Boyd et al. 2011). Individual movement planes of PL, anterior-posterior (PL_{AP}) (MDC 1.71 au), mediolateral (PL_{ML}) (MDC 1.06 au), and vertical (PL_V) (MDC 1.30 au) were recorded and expressed in arbitrary units (au). The percentage contribution of each component plane to overall PL were also calculated; % PL_{AP} (MDC 2.78%), %PL_{ML} (MDC 1.96%), %PLv (MDC 1.95%).

Statistics

To evaluate the sensitivity of each variable standardised changes in the mean (effect size; ES) were calculated between immediately pre, - 24 h (baseline), + 24 h and + 48 h, using a custom spreadsheet (Hopkins 2017). The following criteria were adopted to interpret the magnitude of change; small, >0.2–0.6; moderate, >0.6–1.2; large, >1.2–2; and very large, >2.00 (Hopkins et al. 2009). The magnitude of change was classified as a substantial increase or substantial decrease when there was a 75% or greater likelihood of the effect being equal to or greater than the ES ± 0.2 (small). Changes were classified as unclear when there was a 5% or greater likelihood of the effect being both positive and negative (Hopkins et al. 2009). To further assess if any substantial changes can be considered "real", based on the MDC (75% confidence level) calculated from a reliability study (unpublished observations), a signal: noise (S:N) ratio was calculated (Roe et al. 2016). In order for a variable to be deemed capable of detecting a "real" change, the group mean change +24 h (signal) must be greater than the MDC (noise), as indicated by a ratio >1. This analysis was replicated for weeks one and two. For a variable to

be categorised as having a reproducible fatigue response the S:N ratio had to be >1 for both weeks.

Results

Training load measures recorded during the standardised training session each week are displayed in Table 1. Changes in the mean and effect sizes with magnitude based inferences from baseline to +24 h for the sub-maximal shuttle run test, jump performance and subjective wellness are provided in Tables 2, 3 and 4 respectively.

****INSERT TABLE 1 AROUND HERE****

Sub-maximal shuttle run test

No clear differences were found between baseline and immediately pre training during weeks 1 or 2. During the first week of testing, at +24 h, substantial differences were found for PL_{AP}, PL_{ML}, PL_V, $\%PL_{AP}$, $\%PL_{ML}$ and $\%PL_V$ (Table 2). At +48 h, substantial changes were shown for PL (ES 0.45 ± 0.42 CI, 84% likely positive), PL_{ML} (ES 0.58 ± 0.51 CI, 89% likely positive), $\%PL_{ML}$ (ES 0.37 ± 0.34 CI, 81% likely positive) and $\%PL_V$ (ES -0.52 ± 0.55 CI, 84% likely negative). All other measures displayed no clear differences from baseline at +48 h. During the second week of testing, a reproducible fatigue response at +24 h was shown for PL_{AP}, PL_{ML}, $\%PL_{AP}$, $\%PL_{ML}$ and $\%PL_V$ (Table 2). However, the only measures to display a S:N ratio >1 across both weeks at +24 h were PL_{ML} and $\%PL_V$.

****INSERT TABLE 2 AROUND HERE****

Jump performance

No clear differences were found between baseline and immediately pre training during weeks 1 or 2. During the first week of testing, at +24 h, substantial differences were found for DJ-JH and DJ-RSI (Table 3). At +48 h, substantial increases in jump performance were shown for CMJ (ES 0.44 ± 0.20 CI, 97% very likely positive) and SJ (ES 0.33 ± 0.16 CI, 95% very likely positive). All other measures displayed no differences from baseline at 48 h post. During the second week of testing, a reproducible fatigue response at +24 h was shown for DJ-JH and DJ-RSI (Table 3). However, the only jump performance measure to display a S:N ratio >1 across both weeks at +24 h was DJ-RSI.

****INSERT TABLE 3 AROUND HERE****

Subjective wellness

No clear differences were found in wellness questionnaire responses between baseline and immediately pre training during weeks 1 or 2. No subjective wellness measure was able to show a reproducible fatigue response at any time point. Furthermore, no measure displayed a S:N ratio of >1 at any time point throughout the two week study period.

****INSERT TABLE 4 AROUND HERE****

Discussion

The aim of the current study was to assess the sensitivity of a subjective wellness questionnaire, measures of jump performance and submaximal running performance to training-induced fatigue; and subsequently establish the reproducibility of this training-induced fatigue response. The key findings from the present study were; 1) DJ-RSI, PL_{ML} and $\%PL_V$ were found to be sensitive measures of training-induced fatigue, displaying a reproducible response across both weeks; and 2) CMJ, SJ and all subjective wellness measures were unable to detect

a reproducible fatigue response, potentially calling into question their use in the monitoring of fatigue in athletes.

A novel aspect of the present study is the use of a sub-maximal running test using accelerometer data. A number of variables showed substantial changes at 24 h post training however only PL_{ML} and $\%PL_V$ were able to demonstrate a reproducible response across both weeks of the study. When analysing such accelerometer data, as a surrogate measure of movement strategy, it is important to consider the arbitrary nature of the data and resulting difficulty to discern underlying mechanisms. PlayerLoad™ is the combination of the magnitude (peak acceleration during stance phase) and frequency (number of steps) of the accelerations measured. Reductions in peak ground reaction forces during running have been reported previously (Nikooyan and Zadpoor 2012) when examining the effects of fatigue, as has increased step frequency (Padulo et al. 2012; Girard et al. 2016). Although ground reaction forces and step frequency are not available within the current data it could be speculated that the decrease in vertical acceleration is a result of decreased peak ground reaction forces, and that this reduction supersedes the potential increase in step frequency. The mechanisms behind these changes may be a decrease in lower extremity stiffness which has been associated with a decrease in physical performance and/or increased injury risk (Butler et al. 2003). Future research should look to confirm a link between vertical acceleration ($\%PL_V$) and lower extremity stiffness.

In contrast with the negative changes in $\%PL_V$ there were substantial increases in PL_{ML} at +24 h. Postural control and coordination during running deteriorate with fatigue (McClay and Cavanagh 1994), possibly contributing to the increased mediolateral accelerations found in the present study. This has important implications for practitioners as a reduction in postural control leading to increased acceleration of the trunk, may increase the overall energy cost of running and increase injury risk (Barrett et al. 2016).

The findings from the present study add to the growing body of evident that accelerometer data, specifically vertical and mediolateral movement, are associated with fatigue in team sport athletes (Cormack et al. 2013; Akenhead et al. 2017; Rowell et al. 2018). Practically, this sub-maximal assessment of fatigue is highly applicable to the elite environment. This test uses data which is readily available to practitioners from the MEMS devices routinely worn in training. Further, the sub-maximal nature of the test lends itself to being completed as part of the players' warm-up, meaning a valid assessment of fatigue can be gained with ease on a daily or weekly basis.

The only jump performance measure to show a reproducible response was DJ-RSI. This is in line with previous research which has shown force-time variables such as the flight time: contraction time ratio (Cormack et al. 2008) or RSI (Hamilton 2009) to display a level of sensitivity to changes in training load. Interestingly in the present study, DJ-CT did not show any changes under fatigue, it was reductions in DJ-JH that resulted in the decrement in DJ-RSI. This may indicate that athletes are able to maintain contact time, however, they do not display the same force generating capacity when in a fatigued state, therefore jump height is reduced and consequently DJ-RSI. An important, novel finding in the present study is the link between DJ-RSI and %PL$_V$. Both reactive strength and vertical acceleration may be associated with lower extremity stiffness (Butler et al. 2003; Lloyd et al. 2009), it could therefore be suggested that similar mechanisms of fatigue are causing the reductions it both assessments and further evidence that lower extremity stiffness is and key proponent for physical performance and injury risk.

Other measures of jump performance assessed in the present study, CMJ and SJ, displayed unclear changes when in a fatigued state. This adds further evidence against the use of jump height as a measure of neuromuscular function. It was shown by Gathercole et al. (2015), that

CMJ height was not as sensitive as variables more indicative of CMJ strategy. However, this analysis requires force-time data that involves expensive equipment that may not be readily available to some practitioners. The use of an optical measurement system may be more accessible, thus DJ-RSI could be used as a surrogate force-time measure, which has been shown in the present study to demonstrate a reproducible fatigue response.

Another key finding in the present study is the lack of reproducible response for subjective wellness. Measures of fatigue, sleep quality, muscle soreness and total wellness did show substantial changes in week 1 or 2 of testing however, this response was not replicated across both weeks for any subjective wellness measure. This is in contrast to recent research which has highlighted the superiority of subjective over objective measures, with regards to monitoring fatigue status in athletes (Saw et al. 2015). One potential reason for this is the design of the psychometric questionnaire, used in the present study, to assess subjective wellness. Using a 5-point Likert scale, with 1 point increments, gives a limited number of outcomes which can be selected. A change from a score of 5 to a score of 4 may subjectively not be that great to an athlete, however this is a 20% decrease. Changing the questionnaire to a more continuous scale (e.g. 1-10) may improve the reliability, making detectable changes more accessible and therefore improving the usefulness of subjective wellness measures for monitoring fatigue.

In summary, this study demonstrates the reproducibility of a training-induced fatigue response in elite youth football players. Measurement of jump performance via a DJ-RSI and tri-axial accelerometer variables %PLv and PL_{ML} gained via a sub-maximal shuttle run were found to show a fatigue response greater than the MDC over both weeks of testing. In contrast, no subjective wellness measures displayed a reproducible fatigue response. These data suggest

that a simple assessment of DJ-RSI performance and a sub-maximal shuttle test can be used to accurately detect fatigue in a group of elite youth football players.

Acknowledgments

References

Akenhead R, Marques JB, Paul DJ. 2017. Accelerometer load: a new way to measure fatigue during repeated sprint training? Science and Medicine in Football. 1(2):151-156.

Akenhead R, Nassis GP. 2016. Training load and player monitoring in high-level football: current practice and perceptions. Int J Sports Physiol Perform. 11(5):587-593.

Barrett S, Midgley A, Lovell R. 2014. PlayerLoad™: Reliability, convergent validity, and influence of unit position during treadmill running. Int J Sports Physiol Perform. 9(6):945-952.

Barrett S, Midgley A, Reeves M, Joel T, Franklin E, Heyworth R, Garrett A, Lovell R. 2016. The within-match patterns of locomotor efficiency during professional soccer match play: Implications for injury risk? J Sci Med Sport. 19(10):810-815.

Boyd LJ, Ball K, Aughey RJ. 2011. The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. Int J Sports Physiol Perform. 6(3):311-321.

Brownstein CG, Dent JP, Parker P, Hicks KM, Howatson G, Goodall S, Thomas K. 2017. Etiology and recovery of neuromuscular fatigue following competitive soccer match-play. Front Physiol. 8:831.

Butler RJ, Crowell III HP, Davis IM. 2003. Lower extremity stiffness: implications for performance and injury. Clinical Biomechanics. 18(6):511-517.

Cormack SJ, Mooney MG, Morgan W, McGuigan MR. 2013. Influence of neuromuscular fatigue on accelerometer load in elite Australian football players. Int J Sports Physiol Perform. 8(4):373-378.

Cormack SJ, Newton RU, McGuigan MR, Cormie P. 2008. Neuromuscular and endocrine responses of elite players during an Australian rules football season. Int J Sports Physiol Perform. 3(4):439-453.

De Ste Croix M, Priestley AM, Lloyd RS, Oliver J. 2015. ACL injury risk in elite female youth soccer: Changes in neuromuscular control of the knee following soccer-specific fatigue. Scand J Med Sci Sports. 25(5).

Gathercole RJ, Sporer BC, Stellingwerff T, Sleivert GG. 2015. Comparison of the capacity of different jump and sprint field tests to detect neuromuscular fatigue. J Strength Cond Res. 29(9):2522-2531.

Girard O, Brocherie F, Tomazin K, Farooq A, Morin J-B. 2016. Changes in running mechanics over 100-m, 200-m and 400-m treadmill sprints. J Biomech. 49(9):1490-1497.

Glatthorn JF, Gouge S, Nussbaumer S, Stauffacher S, Impellizzeri FM, Maffiuletti NA. 2011. Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. J Strength Cond Res. 25(2):556-560.

Halson SL. 2014. Monitoring training load to understand fatigue in athletes. Sports Med. 44(2):139-147.

Hamilton D. 2009. Drop jumps as an indicator of neuromuscular fatigue and recovery in elite youth soccer athletes following tournament match play. Journal of Australian Strength and Conditioning. 17(4):3-8.

Hopkins WG. 2017. Spreadsheets for analysis of controlled trials, crossovers and time series. Sportscience; [accessed]. (sportsci.org/2017/wghxls.htm).

Hopkins WG, Marshall S, Batterham A, Hanin J. 2009. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 41(1):3.

Lee CR, Farley CT. 1998. Determinants of the center of mass trajectory in human walking and running. J Exp Biol. 201(21):2935-2944.

Lloyd RS, Oliver JL, Hughes MG, Williams CA. 2009. Reliability and validity of field-based measures of leg stiffness and reactive strength index in youths. J Sports Sci. 27(14):1565-1573.

McCall A, Carling C, Nedelec M, Davison M, Le Gall F, Berthoin S, Dupont G. 2014. Risk factors, testing and preventative strategies for non-contact injuries in professional football:

current perceptions and practices of 44 teams from various premier leagues. Br J Sports Med. 48:1352-1357.

McClay I, Cavanagh P. 1994. Relationship between foot placement and mediolateral ground reaction forces during running. Clinical Biomechanics. 9(2):117-123.

McLean BD, Coutts AJ, Kelly V, McGuigan MR, Cormack SJ. 2010. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. Int J Sports Physiol Perform. 5(3):367-383.

Mendez-Villanueva A, Hamer P, Bishop D. 2008. Fatigue in repeated-sprint exercise is related to muscle power factors and reduced neuromuscular activity. Eur J Appl Physiol. 103(4):411-419.

Mohr M, Krustrup P, Bangsbo J. 2005. Fatigue in soccer: a brief review. J Sports Sci. 23(6):593-599.

Nédélec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G. 2012. Recovery in soccer: Part 1 — Post-Match Fatigue and Time Course of Recovery. Sports Med. 42(12):997-1015.

Nikooyan AA, Zadpoor AA. 2012. Effects of muscle fatigue on the ground reaction force and soft-tissue vibrations during running: a model study. IEEE Trans Biomed Eng. 59(3):797-804.

Padulo J, D'Ottavio S, Pizzolato F, Smith L, Annino G. 2012. Kinematic analysis of soccer players in shuttle running. Int J Sports Med. 33(6):459.

Patterson M, McGrath D, Caulfield B. 2011. Using a tri-axial accelerometer to detect technique breakdown due to fatigue in distance runners: a preliminary perspective. Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE.

Rampinini E, Bosio A, Ferraresi I, Petruolo A, Morelli A, Sassi A. 2011. Match-related fatigue in soccer players. Med Sci Sports Exerc. 43(11):2161-2170.

Roe G, Darrall-Jones J, Till K, Phibbs P, Read D, Weakley J, Jones B. 2016. Between-days reliability and sensitivity of common fatigue measures in rugby players. Int J Sports Physiol Perform. 11(5):581-586.

Rowell AE, Aughey RJ, Clubb J, Cormack SJ. 2018. A Standardised Small Sided Game Can Be Used to Monitor Neuromuscular Fatigue in Professional A-League Football Players. Front Physiol. 9:1011.

Saw AE, Main LC, Gastin PB. 2015. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. Br J Sports Med. 50:281-291.

Scott D, Lovell R. 2017. Individualisation of speed thresholds does not enhance the dose-response determination in football training. J Sports Sci.1-10.

Silva J, Rumpf M, Hertzog M, Castagna C, Farooq A, Girard O, Hader K. 2018. Acute and residual soccer match-related fatigue: a systematic review and meta-analysis. Sports Med.1-45.

Taylor K, Chapman D, Cronin J, Newton MJ, Gill N. 2012. Fatigue monitoring in high performance sport: a survey of current trends. Journal of Australian Strength and Conditioning. 20(1):12-23.

Thomas K, Dent J, Howatson G, Goodall S. 2017. Etiology and recovery of neuromuscular fatigue following simulated soccer match-play. Med Sci Sports Exerc. 49(5):955-964.

Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. 2015. Monitoring fatigue during the in-season competitive phase in elite soccer players. Int J Sports Physiol Perform. 10(8):958-964.

Twist C, Highton J. 2013. Monitoring fatigue and recovery in rugby league players. Int J Sports Physiol Perform. 8(5):467-474.

Table 1. Descriptive statistics (mean ± SD) for standardised training loads.

	Week 1	Week 2	CV	ES (MBI)
TD	7242 (±532)	7221 (±514)	5.5%	-0.04 (*Unclear*)
VHSR	597 (±85)	591 (±71)	8.7%	-0.07 (*Unclear*)
SPR	325 (±58)	318 (±63)	9.1%	-0.11 (*Unclear*)
AD Load	544 (±75)	534 (±64)	7.0%	-0.13 (*Unclear*)

Note: TD: total distance, VHSR: very high speed running, SPR: sprinting, AD Load: acceleration and deceleration load, CV: coefficient of variation, ES: effect size, MBI: magnitude based inference.

Table 2.
Sensitivity 24 hours post training for PlayerLoad™ (PL), individual component planes; anterior-posterior (PL_{AP}),
mediolateral (PL_{ML}), and vertical (PL_V), and the % contribution of each plane.
Change in mean ± SD; effect size (ES) ± 90% confidence intervals with magnitude based inference (MBI); signal: noise
ratio.

		Baseline	24 h Post	Δ in Mean	ES	MBI	S:N Ratio
PL	Week 1	38.67 (± 3.50)	39.73 (± 4.82)	1.06 (± 2.55)	0.28 ± 0.68 (Small)	58% Possible Increase	0.77
	Week 2	38.47 (± 4.02)	40.66 (± 3.88)	2.19 (± 1.94)	0.51 ± 0.45 (Small)	88% * Likely Increase	1.59 **
PL_{AP}	Week 1	13.67 (± 2.24)	15.42 (± 4.14)	1.75 (± 2.00)	0.67 ± 0.77 (Moderate)	85% * Likely Increase	1.03 **
	Week 2	13.58 (± 2.23)	15.00 (± 2.92)	1.42 (± 1.30)	0.59 ± 0.54 (Small)	89% * Likely Increase	0.83
PL_{ML}	Week 1	13.33 (± 1.87)	14.42 (± 2.11)	1.08 (± 1.05)	0.54 ± 0.52 (Small)	87% * Likely Increase	1.02 **
	Week 2	13.50 (± 1.38)	14.75 (± 1.36)	1.25 (± 0.97)	0.84 ± 0.34 (Moderate)	100% * Most Likely Increase	1.18 **
PL_V	Week 1	28.33 (± 2.50)	27.08 (± 2.81)	-1.25 (± 1.58)	-0.47 ± 0.59 (Small)	78% * Likely Decrease	-0.96
	Week 2	28.08 (± 2.35)	27.25 (± 3.19)	-0.83 (± 2.44)	-0.33 ± 0.50 (Small)	67% Possible Decrease	-0.64
% PL_{AP}	Week 1	24.6% (± 2.6%)	26.7% (± 3.6%)	2.1% (± 1.5%)	0.76 ± 0.53 (Moderate)	96% * Very Likely Increase	0.77
	Week 2	24.2% (± 2.0%)	26.2% (± 3.5%)	2.0% (± 1.9%)	0.95 ± 0.88 (Moderate)	92% * Likely Increase	0.73
% PL_{ML}	Week 1	24.1% (± 2.6%)	25.4% (± 2.4%)	1.3% (± 1.3%)	0.46 ± 0.47 (Small)	83% * Likely Increase	0.66
	Week 2	25.5% (± 2.0%)	26.0% (± 2.6%)	0.5% (± 1.1%)	0.24 ± 0.49 (Small)	56% * Possible Increase	0.27
% PL_V	Week 1	51.3% (± 2.5%)	47.9% (± 3.7%)	-3.4% (± 1.7%)	-1.27 ± 0.62 (Large)	100% * Almost Certain Decrease	-1.76 **
	Week 2	50.3% (± 2.9%)	47.8% (± 4.3%)	-2.6% (± 2.6%)	-0.82 ± 0.84 (Moderate)	89% * Likely Decrease	-1.31 **

* A substantial increase or decrease classified as ≥75% likelihood of the effect being greater than or equal to the ES ± 0.2 (small).

** Signal: Noise Ratio > 1.00 or < -1.00; variable has the ability to detect "real" change.

Table 3.
Sensitivity 24 hours post training for jump tests; countermovement jump height (CMJ), squat jump height (SJ), drop jump contact time (DJ-CT) drop jump height (DJ-H) and drop jump reactive strength index (DJ-RSI).
Change in mean ± 90% CI; effect size (ES) ± 90% CI with magnitude based inference (MBI); signal: noise ratio.

		Baseline	24 h Post	Δ in Mean	ES	MBI	S:N Ratio
CMJ	Week 1	35.18 (±4.92)	35.28 (±4.56)	0.10 (±1.01)	0.02 ± 0.19 (Trivial)	91% Likely Trivial	0.04
	Week 2	36.18 (±3.85)	35.74 (±4.06)	-0.44 (±1.09)	-0.11 ± 0.26 (Trivial)	Unclear	-0.18
SJ	Week 1	34.04 (±5.31)	33.07 (±5.31)	-0.97 (±0.86)	-0.17 ± 0.15 (Trivial)	Unclear	-0.43
	Week 2	34.92 (±4.01)	34.58 (±3.68)	-0.34 (±1.19)	-0.08 ± 0.28 (Trivial)	Unclear	-0.15
DJ-CT	Week 1	0.206 (±0.029)	0.208 (±0.016)	0.001 (±0.013)	0.04 ± 0.42 (Trivial)	Unclear	0.09
	Week 2	0.203 (±0.030)	0.206 (±0.029)	0.003 (±0.004)	0.10 ± 0.13 (Trivial)	92% Likely Trivial	0.21
DJ-H	Week 1	29.18 (±5.55)	26.06 (±3.47)	-2.74 (±1.50)	-0.46 ± 0.25 (Small)	96% * Very Likely Decrease	-0.99
	Week 2	29.44 (±4.83)	26.75 (±4.15)	-2.69 (±1.43)	-0.52 ± 0.28 (Small)	97% * Very Likely Decrease	-0.97
DJ-RSI	Week 1	1.45 (±0.35)	1.29 (±0.24)	-0.16 (±0.09)	-0.43 ± 0.25 (Small)	94% * Likely Decrease	-1.00 **
	Week 2	1.50 (±0.38)	1.34 (±0.34)	-0.16 (±0.08)	-0.40 ± 0.19 (Small)	96% * Very Likely Decrease	-1.01 **

* A substantial increase or decrease classified as ≥75% likelihood of the effect being greater than or equal to the ES ± 0.2 (small).

** Signal: Noise Ratio > 1.00 or < -1.00; variable has the ability to detect "real" change.

Table 4.
Sensitivity 24 hours post training for subjective wellness measures.
Change in mean ± SD; effect size (ES) ± 90% confidence intervals with magnitude based inference (MBI); signal: noise (S:N) ratio.

		Baseline	24 h Post	Δ in Mean	ES	MBI	S:N Ratio
Fatigue	Week 1	3.00 (±0.85)	2.83 (±0.72)	-0.17 (±0.49)	-0.18 ± 0.53 (Trivial)	Unclear	-0.36
	Week 2	3.25 (±0.62)	3.00 (±0.60)	-0.25 (±0.23)	-0.37 ± 0.35 (Small)	80% * Likely Decrease	-0.53
Sleep Quality	Week 1	3.92 (±0.29)	3.58 (±0.67)	-0.33 (±0.40)	-1.07 ± 1.30 (Moderate)	87% * Likely Decrease	-0.36
	Week 2	3.67 (±0.49)	3.58 (±0.79)	-0.08 (±0.47)	-0.16 ± 0.88 (Trivial)	Unclear	-0.09
Muscle Soreness	Week 1	3.17 (±0.83)	2.33 (±0.49)	-0.83 (±0.37)	-0.93 ± 0.41 (Moderate)	100% * Most Likely Decrease	-0.88
	Week 2	2.67 (±0.78)	2.33 (±0.65)	-0.33 (±0.51)	-0.40 ± 0.61 (Small)	Unclear	-0.35
Stress	Week 1	3.33 (±0.78)	3.17 (±0.83)	-0.17 (±0.37)	-0.20 ± 0.44 (Small)	Unclear	-0.18
	Week 2	3.33 (±0.78)	3.50 (±0.80)	0.17 (±0.58)	0.20 ± 0.69 (Small)	Unclear	0.18
Mood	Week 1	3.83 (±0.58)	3.75 (±0.62)	-0.08 (±0.35)	-0.13 ± 0.56 (Trivial)	Unclear	-0.09
	Week 2	3.67 (±0.78)	3.75 (±0.75)	0.08 (±0.60)	-0.10 ± 0.72 (Trivial)	Unclear	0.09
Total Wellness	Week 1	17.25 (±2.18)	15.67 (±1.97)	-1.58 (±1.39)	-0.68 ± 0.59 (Moderate)	91% * Likely Decrease	-0.62
	Week 2	16.58 (±1.83)	16.17 (±2.29)	-0.42 (±1.47)	-0.21 ± 0.75 (Small)	Unclear	-0.16

* A substantial increase or decrease classified as ≥75% likelihood of the effect being greater than or equal to the ES ± 0.2 (small).

** Signal: Noise Ratio > 1.00 or < -1.00; variable has the ability to detect "real" change.