Can the Use of an External: Internal Ratio During Standardised Small-Sided Games be a Detector of Fatigue in Professional Adolescent Soccer Players?

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Abstract: *The aim of the investigation was to explore whether the external: internal (E: I) ratio during a standardised small-sided game (SSG) was impacted by fatigue monitoring methods in professional adolescent soccer players. Ten professional male soccer players (Mean ± SD; Age: 19.6 ± 1.4 years) data from seven standardised SSG's (6v6+GK, 2x4 min, 40 x 35m) were analysed during the study. Total distance (TD):Heart rate exertion (HRe), PlayerLoad^{TM} (PL): HRe and Explosive distance (ED): HRe were the E: I ratio's analysed from the SSG's. Morning perceived wellness score, using a customised self-report questionnaire (energy levels, sleep and muscle soreness), and Flight time: Contraction time (FT:CT), taken from a counter-movement jump (CMJ) performed prior to training, were used as markers of fatigue in the study. A Z-score of -1 was considered 'fatigued'. Mixed-effect linear models revealed a significant effect for perceived wellness Z-score on TD: HRe, PL: HRe and ED: HRe, which resulted in a small increase in all E: Iratios. FT: CT Z-score resulted in a non-significant, trivial effect on TD: HRe, PL: HRe and ED: HRe. The results suggest E:I ratios are influenced by subjective fatigue, thus, E: I ratio's may be a non-invasive tool for fatigue detection. However, caution should be taken when interpreting an increase in E:I ratio, and, therefore, the use of E: I ratio's as a means for fatigue detection requires further investigation.*

Keywords: *Football,Fatigue,Monitoring, GPS, External: Internal ratio.*

Abbreviations(*In order of appearance in text*): *Creatine Kinase (CK), Counter-Movement Jump (CMJ), Global Positioning Systems (GPS), Heart Rate (HR), Total Distance (TD), External: Internal (E:I), Standard Deviation (SD), Small-sided game (SSG), PlayerLoad^{TM} (PL), Explosive Distance (ED),Heart Rate Exertion (HRe), Flight Time: Contraction Time (FT:CT).*

1. INTRODUCTION

High seasonal injury-rates, resulting in players being unavailable for team selection, may elicit a large financial burden and has been negatively associated with team performance in soccer [1]. As a result, a principle role of Sport Science and Medical practitioners is to assist in making the strongest team available for selection throughout the season [2]. Professional soccer players are typically exposed to at least four training sessions and one competitive match per-week throughout the season [3]. In accordance with Banister [4], each training session or match produces both a positive fitness response and a negative fatigue response, with an athlete's performance being a result of their fitness minus their accrued fatigue. Periods of stressful training and match-play without sufficient recovery will ultimately result in an

accumulation of fatigue [5], which, as proposed by Banister [4], has the potential to reduce a player's performance and also increase their relative risk of sustaining an injury [6]. Indeed, fatigue has been shown to reduce physical training outputs throughout a competitive season in elite soccer players [7,8]. Being able to regularly assess the level of fatigue of players within team-sports may provide practitioners with an objective insight into how the player has responded to a previous training stimulus, and consequently responds to a new training stimulus. This may augment future training and recovery prescription so that a player can remain healthy and perform at their highest level throughout the season [9].

Creatine Kinase (CK) concentrations and indices of Counter-Movement Jump (CMJ) have been extensively used throughout the literature

as markers of fatigue [8, 10]. Undoubtedly, both techniques provide an objective assessment of fatigue, with significant changes compared to baseline in both CK concentrations and indices of CMJ being observed following soccer match-play [10]. However, the implementation of both techniques within real-world settings is not without challenge to the practitioner. For example, assessing CK concentrations has significant cost implications, and is also considered invasive and time-consuming, requiring blood samples to be taken from players [11]. Similarly, although non-invasive, the regular implementation of CMJ's throughout a large squad may also be time-consuming and it is essential players are motivated to produce a maximal effort, which is not easy in practice [11]. Strong player compliance and education is also required when implementing subjective self-report fatigue questionnaires, as it has been suggested findings may not truly reflect a player's perception of fatigue, with players answering in a 'socially desirable' manner to detract attention from themselves [11, 12].

The aforementioned limitations confirm a more practical means of monitoring fatigue within a team-sport environment is may be required. Indeed, Carling et al. [11] has suggested practitioners should strive for monitoring systems that are instantaneous and 'invisible' to players, using data derived from training sessions. Global position systems (GPS) and Heart Rate (HR) monitors are widely implemented within professional team-sport environments to quantify the training load [13]. It has been suggested that integrating GPS derived external loads (i.e. Total Distance (TD)) with internal loads (i.e. iTrimp) to form an External:Interal (E:I) ratio (i.e.TD:iTrimp), may offer a constant and non-invasive assessment of an individual's fitness and fatigue, by providing an indication of the work performed (external load) and the cost of performing that work (internal load) [12]. In support of using integrated external and internal loads, Akubat, Barrett and Abt [14] reported an E:I ratio of TD and iTrimp was strongly related (r = .69, P = 0.03) to measures of aerobic fitness in soccer players during a soccer specific simulation protocol, with a greater ratio being associated with increased levels of fitness. More recent research using rugby players [15, 16] has also found the E:I ratio to be strongly related to aerobic fitness (r= 0.63, P < 0.05) as well as being able to detect changes in fitness during

skill based activities (i.e. small-sided games), further enhancing the practical applicability of the E:I ratio. Whilst the aforementioned studies did not assess whether the ratio was associated with fatigue, Delaney et al. [16] did identify large fluctuations in the E:I ratio between sessions and suggested that this may be attributed to fatigue, therefore, providing an avenue for the E:I ratio to be used as a potential detector of fatigue. Supporting the assumptions of Delaney et al. [16], Akubat, Barrett, Sagarra and Abt [17] reported a significant change in the E:I ratio during a soccer-specific protocol performed in both a rested and fatigued state. Paradoxically, the study found the ratio (TD:iTrimp) to moderately increase during the fatigued state (30.10 vs. 37.71 au, P < 0.01). Whilst TD decreased, as expected during the fatigued state, the internal load, iTrimp, also decreased, and at a larger magnitude than that of total distance. This finding challenges the hypothesis that during a fatigued state, individuals will likely experience a greater internal cost per unit of external work [12]. The authors of the study [17] attributed this finding to a supressed HR response, which is synonymous in over-reached athletes [18]. However, it could be argued whether the athletes in the study did experience over-reaching symptoms following just one exercise session [5]. Further research of the E:I ratio as an assessment of fatigue is therefore warranted. Similarly, it would be of greater interest to assess the ratio during common training activities in soccer, rather than match-play simulations.

Therefore, the purpose of the study is to further explore whether the E:I ratio, derived through commonly used player monitoring methodologies and training drills, may be associated with neuromuscular and subjective fatigue in professional soccer players.

2. METHODS

2.1. Participants

Ten professional male soccer players (Mean ± Standard deviation (SD)); Age: 19.6 ± 1.4 years; Body Mass: 74.4 ± 8.7 kg; Height: 180.5 ± 5.3 cm) competing in the 2018/19 professional development league, provided written informed consent, allowing for their data to be collected and analysed. Seven standardised small-sided games performed over an 8-week period during the in-season competitive phase were analysed. The participants were familiar with all

experimental procedures, as these were a part of normal day-to-day practice.

2.2. Experimental Procedures

Standardised Small-Sided Game

A standardised 6v6 + Goalkeepers small-sided game (SSG) was used throughout the duration of the 8-week study period. The SSG was played within a 40 m x 35 m area on natural turf. 2 x 4 min work periods interspersed with 90 s recovery were analysed. No rule restrictions were implemented within the games. Team selection was dictated by the coaches and altered throughout the duration of the study. The SSG's were performed at different stages of the weekly cycle (i.e. Matchday -1, -3 or -4), but were always at the end of the training session. However, drills preceding the SSG were not standardised (i.e. warm up, passing and possessions).

External and Internal load

Throughout all seven training sessions, athletes were assigned a 10Hz GPS unit integrated with a 100 Hz accelerometer (Viperpod, Statsports, Ireland). The units were positioned between the scapulae, using a tightly fitted, secured vest. Each player wore the same device for each session to avoid inter-unit error [19]. The variables selected to reflect external load were TD (m), PlayerLoad^{TM}(PL) (au) and Explosive distance (ED) (m). Both TD (CV = 10.5%) and PL(CV = 11.03%) have been shown to be valid and reliable measures when using E:I ratios[15,17]. ED, which is the cumulative distance an individual has spent accelerating and decelerating >2 m/s, is a novel measure within the E:I ratio and has been selected due to its association with a greater physiological cost than that of high-speed linear running [20]. Players also wore HR monitors (T31, Polar, Finland) throughout the seven sessions. These were placed in direct contact with the skin, firmly fitted around the chest. A novel measure of HR exertion (HRe), calculated using Statsports Viper Software (Viper 2.6.0.0, Statsports, Ireland), has been selected as the measure for internal load. HRe represents the total volume of cardiovascular exertion an individual will experience relative to time. The HR recorded is split into weighted zones that are relative to the individuals HR max (identified during maximal testing in pre-season). HR zones closer to an individual's HR max are

associated with a greater weighting score. The duration (in seconds) the HR is spent in that zone is then multiplied by the weighting score for that zone. The value from each zone is then totalled which provides the overall HRe score for that drill (Statsport Technologies, 2012).

External: Internal Ratio

The E:I ratio was calculated using the same method as that of Akubat et al. [14]. It is simply the external load divided by the internal load.

E: I Ratio (au) = external load/internal load

TD: HRe, PL: HRe and ED: HRe were the ratio's explored in the present study.

Neuromuscular Fatigue

Prior to the training session, each player performed two maximal CMJ's on a force plate (FD4000s, ForceDecks, United Kingdom). Players self-selected their counter-movement depth and were cued to jump as high as possible whilst keeping hands placed on their hips. Jump height (cm) and Flight time: Contraction time (FT:CT)(s), derived through integrated system software within the force plate (FD4000s, ForceDecks, United Kingdom), were the variables selected, as they have been deemed valid and reliable measures of neuromuscular fatigue (CV = 8%) [21]. FT: CT scores were reported relative to the individual's absolute average and normal variation from the duration of the study period, by reporting them as Z-scores (individual player's score – individual player's average / individual player's standard deviation). A FT: CT Z-score of -1 may be considered as 'fatigue' [8].

Subjective Fatigue

Players were required to complete a customised, perceived wellness questionnaire before training (Appendix A). It has been shown that self-report questionnaires may be a valid means of assessing fatigue [22]. Perceived muscle soreness, energy levels and sleep were the items included in the questionnaire. Players were required to answer using a Likert scale of 1-7, with a 1 score being classed as very, very poor and 7 being very, very good. The scores from the three questions were then averaged to provide an 'overall wellness score'. Overall wellness scores were also reported as Z-scores. A wellness Z-score of -1 may be considered as 'fatigue' [7].

Statistical Analysis

To examine the effect of perceived wellness and FT: CT Z-score on the external and internal loads and E: I ratio's during the SSG's, mixed-effect linear models were performed using SPSS (IBM, SPSS, Version 24.0.0). Perceived wellness and FT: CT Z-score were entered as fixed effects, with Subject ID entered as a random effect. The coefficient of wellness Z-score and FT: CT Z-score was then taken as the value of the effect of perceived wellness and FT: CT on the corresponding E: Iratios. Statistical significance was set at the $P < 0.05$ level. The magnitudes of the effects were reported as Cohen's effect sizes (*d*) with *d* described as < 0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, 2.0–4.0 very large (Hopkins, 2002)

3. RESULTS

The mean ± SD performance loads during the seven standardised SSG's are presented in Table 1.

Table1. *Mean ± SD performance loads of professional soccer players (n=10) during 7 standardised small-sided games*

Load Parameters	
TD (m)	1071.6±108.5
PL (au)	14.8 ± 0.8
ED (m)	186.0 ± 15.5
HRe (au)	42.3 ± 6.1
TD:HRe (au)	27.4 ± 8.1
PL:HRe (au)	0.37 ± 0.1
ED:HRe (au)	4.75 ± 1.7

Subjective Fatigue

Table 2 summarises the results of the mixed-effect linear models for perceived wellness on the external and internal loads, and the E: Iratios. The mixed-effect linear models demonstrate a significant effect for perceived wellness Z-score on HRe ($P < 0.05$), TD:HRe, PL:HRe and ED:HRe ($P < 0.001$), but no significant effect for perceived wellness on any of the external loads in isolation. The coefficient of the fixed effect test revealed that a perceived wellness Z-score of -1 would correspond to a decrease in HRe of 4.10 ± 1.25 au, but an increase in TD:HRe of 3.16 ± 0.70au, PL:HRe of 0.04 ± 0.01 au and ED:HRe of 0.48± 0.01 au. The size (*d*) of the decrease in HRe and increase in all E: Iratios was small.

Table2. *The model intercept and Z-score coefficient for the fixed effect test of perceived wellness on external and internal loads and E:I ratio's, along with the effect size (d) and descriptor of a perceived wellness Z-score of -1 on the external and internal loads and external: internal ratio's*

Parameters	Model Intercept	Coefficient	Effect Size (*d*)	Descriptor
TD (m)	1071.67 ± 24.24	4.47 ± 10.40	0.04	Trivial
PL (au)	14.81 ± 0.62	0.18 ± 0.19	0.06	Trivial
ED (m)	186.01 ± 0.01	0.58 ± 4.02	0.02	Trivial
HRe (au)	42.26 ± 2.49	4.10 ± 1.25*	0.32	Small
TD:HRe (au)	27.41 ± 1.61	-3.16 ± 0.7*	0.39	Small
PL:HRe (au)	0.37 ± 0.20	-0.04 ± 0.01*	0.40	Small
ED:HRe (au)	4.75 ± 0.39	-0.48 ± 0.1*	0.29	Small

*Denotes a significant effect P < 0.001

** Denotes a significant effect P < 0.05

Neuromuscular Fatigue

Table 3 summarises the results of the mixed-effect linear models for FT: CT on the external and internal loads and E: Iratios. Mixed-effect linear models revealed a non-significant effect for FT: CT Z-score on all external and internal loads, and also TD: HRe, PL: HRe and ED: HRe. The coefficient of the fixed effect test revealed that a FT: CT Z-score of -1 would correspond to an increase in TD: HRe of 1.32±1.80 au, PL: HRe of 0.01± 0.01 au and ED: HRe of 0.23± 0.14 au. The size (*d*) of the increase in all ratio's was trivial.

Table3. *The model intercept and Z-score coefficient for the fixed effect test of flight time: contraction time on external and internal loads and the E:I ratio's and the effect size (d) and descriptor of a flight time: contraction time Z-score of -1 on the external and internal loads and external: internal ratio's*

Parameters	Model Intercept	Coefficient	Effect Size (d)	Descriptor
TD (m)	1071.67 ± 24.24	-0.94 ± 10.35	0.01	Trivial
PL (au)	14.81 ± 0.62	-0.16 ± 0.19	0.03	Trivial
ED (m)	186.01 ± 0.01	-0.50 ± 4.02	0.01	Trivial
HRe (au)	42.26 ± 2.49	1.27 ± 1.35	0.09	Trivial
TD:HRe (au)	27.47 ± 1.65	-1.32 ± 1.8	0.16	Trivial
PL:HRe (au)	0.37 ± 0.02	-0.01 ± 0.01	0.09	Trivial
ED:HRe (au)	4.78 ± 0.39	-0.23 ± 0.14	0.14	Trivial

4. DISCUSSION

The aim of the current study was to assess whether pre-training fatigue monitoring methods impact upon E: I load ratios during standardised SSG's, thus, presenting a potential avenue for E:I ratios to be used as a fatigue monitoring tool. The study found a significant effect (P < 0.001) for pre-training perceived wellness Z-score on TD: HRe, PL: HRe and ED: HRe. FT: CT Z-score showed no significant effect on any of the E: I ratio's during the study. A wellness Z-score of -1, which may reflect fatigue [7,8], corresponded to a 3.16 ± 0.70au (*d* = 0.39) increase in TD:HRe, a 0.04 ± 0.01 au (*d* = 0.40) increase in PL:HRe, and a 0.48 ± 0.10 au (*d* = 0.29) increase in ED:HRe.

From an external and internal load viewpoint, it has been hypothesised that fatigue would elicit a greater internal cost per unit of external work [12], thus, resulting in a lower E:I ratio. In contrast, the findings from the current study show that a significant increase of the E: Iratios would occur under subjective fatigue (-1 Wellness Z-score).Whilst the findings contradict with the hypothesis, they do support the work of Akubat, Barrett, Sagarra and Abt[17] who also reported an increase in both TD: iTrimp and PL: iTrimp in a 'subjective' fatigued state compared to a rested state. The increase in the E:I ratio during Akubat, Barrett, Sagarra andAbt's [7] study was the result of the internal load decreasing at a larger magnitude than that of the external load. Whilst the current study did not directly compare a fatigued state to a rested state like that of the aforementioned study, mixed-effect linear models did reveal perceived wellness Z-score to have a significant (P < 0.05) effect on the internal load HRe, but no significant effect (P > 0.05) on any of the external load parameters. A perceived wellness Z-score of -1 resulted in HRe decreasing by

4.10± 1.25 au. Therefore, the increase in E:I ratio under subjective fatigue during this study may also be as a direct result of a decreased internal response, rather than any significant changes to the external load. A supressed HR response is synonymous in over-reached athletes [18]. It is feasible that the players involved in the current study may have experienced over-reaching during the 8-week study period, thus, resulting in the decreased internal response during the SSG's. If this is the mechanism through which such changes are seen in the E: I ratio's, then E: Iratios may hold value as a fatigue monitoring tool. However, whilst the present findings suggest that fatigue will lead to decreased HR response, thus, resulting in an increase in E:I ratio, it should be noted that a decreased HR response to exercise is also associated with improved fitness [23]. Indeed, research has also shown that a relationship exists between aerobic fitness and E:I ratios, with an increase in aerobic fitness corresponding to an increase in the E:I ratio [14, 16]. Unfortunately, due to the competition schedule, the study was unable to undertake any aerobic fitness testing during the study period. However, it is highly plausible that the players may have improved their fitness during this time. Therefore, caution should be taken when interpreting the results from the present study, as it cannot be disregarded that the above results may have been influenced through improved levels of aerobic fitness, rather than fatigue *per se*.

No effect was found for neuromuscular fatigue (FT: CT Z-score) on any of the E: Iratios. Therefore, the E:I ratio may not be an appropriate tool to signify if an athlete is experiencing neuromuscular fatigue. Previous studies have shown neuromuscular fatigue (i.e. decrease in FT: CT and jump height) to decrease

external training outputs (i.e. TD) within standardised SSG's [8, 24]. Therefore, it was hypothesised that neuromuscular fatigue would decrease external load, which in-turn would result in a decreased E:I ratio. However, mixed model analysis revealed no significant effect for neuromuscular fatigue on any of the external or internal load parameters, thus, no significant effect on the E:I ratio. A possible explanation for this outcome may be due to the periodisation of the jump testing and SSG's. The jump testing and standardised SSG's typically took place greater than 72 hours post-match. By this time, neuromuscular fatigue will have generally returned to baseline [25]. As the current study used Z-scores based on the individual's absolute average and normal variation from the duration of the study period, a Z-score of -1 may not truly reflect fatigue. Had the study period been of a greater duration, or the periodisation of testing and SSG's been less than 72 hours post-match, an effect for neuromuscular fatigue may have occurred. Indeed, perceptual fatigue, such as that of perceived wellness, typically takes longer than 72 hours post-match to return to baseline [25]. This may explain why a significant effect was observed for perceived wellness Z-score and not neuromuscular fatigue in the current study.

The results of this study should be viewed as an exploratory starting point rather than a definitive diagnostic tool. The fact that E:I ratio's may lack sensitivity to neuromuscular fatigue, and the ambiguity when determining whether changes in the E:I ratio are as a result of fatigue or improved fitness highlights the current issues with using the E:I ratio as a fatigue monitoring tool. It could be deemed too early for practitioners to begin implementing the E:I ratio confidentially within their monitoring practices. Further researched is required using both fitness and fatigue measures throughout the duration of a competitive season, using a variety of drills, in order to provide smallest worthwhile changes and meaningful inferences, so practitioners can confidently ascertain whether changes in the E:I ratio are a result of fitness or fatigue.

5. CONCLUSION

Practitioners should strive for fatigue monitoring systems that are instantaneous and

'invisible' to players, using data derived from training sessions.

The significant effect observed between perceived wellness and TD: HRe, PL: HRe and ED: HRe during the SSG's provide scope for E:I ratio's to be used as a 'invisible' fatigue detection tool. Should an increase in an individual's E:I ratio occur, which would be indicative of fatigue, a practitioner may implement recovery strategies to alleviate the fatigue. However, the lack of significant effect of FT: CT on all E: Iratios suggest that they may not be an appropriate method to determine neuromuscular fatigue. Additionally, a practitioner cannot confidently ensure that the increase in E:I ratiois as a result of fatigue or increased levels of aerobic fitness within the players. Whilst this study offers potential for the E:I ratio as a fatigue monitoring tool, the ambiguity determining whether the change in ratio is a result of fatigue or increased levels of fitness, and its inability to determine neuromuscular fatigue highlights the current issues with the E:I ratio. Therefore, the E:I ratio requires further research before it should be implemented within professional monitoring practices.

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APPENDIX A

Subjective Wellness Questionnaire

How are your energy levels today?						
1	2	3	4	5	6	7
Very, Very Poor	Very Poor	Poor	Okay	Good	Very Good	Very Very Good
How was your sleep quality last night?						
1	2	3	4	5	6	7
Very, Very Poor	Very Poor	Poor	Okay	Good	Very Good	Very Very Good
How is your overall muscle condition?						
1	2	3	4	5	6	7
Very, Very Sore	Very Sore	Slightly Sore	Okay	Good	Very Good	Very Very Good