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Measuring and Monitoring Training-Induced Subjective Fatigue During a Collegiate Soccer Pre-season: A Case Study

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Abstract

Quantifying and monitoring training load in athletes is crucial to ensure optimal competitive performance. In this case study, we assessed the relationship between training load and subjective fatigue in intercollegiate soccer over the course of the pre-season period. We did not find meaningful relationships ($r<0.5$) between training load and fatigue, limited by the precision of our measures. However, there may be differences in mental and physical fatigue responses between individuals. Therefore, it may be important for coaches and practitioners to differentiate between physical and mental fatigue, while accounting for individual differences, when monitoring subjective training load.

Introduction

Intercollegiate athletics impose both physical and psychological stressors upon the athletes. The type and magnitude of this stress are dependent upon the frequency, duration, and intensity of training and competition, and furthermore upon each athlete's individual response[1]. In turn, this imposed stress dictates the nature of the training adaptations that occur[2]. Because performance in competitive sport is a cornerstone over other health or fitness outcomes, it is crucial that these training adaptations are purposeful and sport-specific. These adaptations run along a continuum of too little training stress (resulting in detraining) to too great training stress (resulting in overtraining and maladaptations). Optimal performance falls in the middle, a delicate balance between fitness and fatigue that results in readiness to compete. With this relationship in mind, it is crucial to design a training program that will maximize performance and minimize fatigue for competition.

In order to do this, practitioners have used numerous evidence-based methods to quantify training stress and monitor fatigue in their athletes. Training stress is quantified through training load (TL), defined as the product of training volume (duration times frequency) and training intensity. TL can be divided into two categories: 1) external TL, defined as the objective physical work performed, such as distance run; and 2) internal TL, defined as the physiological stress imposed by the external load, such as VO_2 or heart rate[3]. Importantly, internal TL has direct implications for training adaptations, increasing its relevance in eliciting the desired performance outcomes[4]. Fatigue imposed by TL can then be measured using subjective measures, biochemical analyses, or performance tests, all of which have important implications for readiness to compete. Additionally, training-induced fatigue can be reflected in abstract psychological variables such as mood, motivation, and stress. Researchers and practitioners have used combinations of these methods to manage athletes in the competitive, off-season, and pre-competitive periods for a variety of sports.

As a prevalent sport both worldwide and in the National Collegiate Athletic Association (NCAA), the physical demands of soccer have been well documented; however, the optimal methods to monitor performance and measure training-induced fatigue in this sport remain elusive. While past researchers have used a combination of objective and subjective measures[1-6], many of these methods can be costly, time-consuming, easily misinterpreted, require substantial expertise, or have great variation either within or between individuals, all of which deem them unfeasible and ineffective. In fact, because of the diverse nature of the sport and its athletes, one single, comprehensive measure may not exist. In light of this, researchers and practitioners alike continue to search for the fewest number of measures at that are the most simple and cost-effective to use that will provide the most pertinent and useful information on player fitness and fatigue. This need for simple measures of athlete readiness becomes especially important in college soccer, where the playing season is condensed and the operating budget is minimized in comparison to professional clubs. Additionally, this becomes more relevant during the pre-competitive period, where training load is maximized and there are no NCAA-mandated restrictions on hours of training per week.

Rated Perceived Exertion (RPE) has been used as an inexpensive and convenient means to measure perceptual training-induced fatigue. RPE can be used in favor of common heart rate-based methods, which may underestimate the plyometric or anaerobic components of soccer that are crucial to performance[7]. Furthermore, session-RPE (sRPE, the product of RPE and training duration, in minutes) has been proposed as a means to quantify global training stress, shown to correlate with heart rate-based methods[7]. Foster et al.[7] found that sRPE had a similar pattern of response to summated heart rate zones in a wide variety of activities, and Borresen and Lambert[5] attributed 71% of the variance in sRPE to these summated zones. Impellizzeri et al.[4] found sRPE to be correlated not only to summated heart rate zones ($r=0.54$-0.78, $p<0.01$), but also to heart rate zones specific to each individual's ventilatory threshold ($r=0.61$-0.85, $p<0.01$).

However, these methods come with their limitations; RPE has been shown to correlate more strongly with consciously perceptible aspects of fatigue, such as heart rate, skin temperature, breathing rate, or perception of pain[8]. sRPE may not be as accurate for subjects who perform mostly high or mostly low intensity exercise[5]. As well, RPE does not differentiate between the physical and mental aspects of fatigue, and mental aspects of fatigue (such as decreased mood or increased stress) may potentiate these physical responses and/or the perceived training load. This attests that age, gender, external life stressors, environmental factors, intensity of exercise, or personality types may play a role in the global RPE response.

Despite these limitations, RPE-based methods have been used with success to monitor internal TL and subsequent performance in professional[9] or competitive club[4] soccer athletes, but have not been examined in female collegiate athletes. Additionally, the effects of sRPE on fatigue status, including the respective physical and mental aspects, have not been well characterized. In order to further examine the merit of this simple, subjective measure of TL and how it effects both the physical and mental aspects of training-induced fatigue, we performed a case study examining sRPE versus ratings of subjective fatigue in female collegiate soccer players during the pre-competitive period. We expected to find a negative correlation between TL and readiness to play, in that as TL increased at any point during pre-season, subsequent readiness to play (reflected in the following day's questionnaire) would decrease.

Methods

Experimental Approach to the Problem

In this case study, we monitored TL (sRPE) and subjective fatigue responses (daily global fatigue questionnaires) in three collegiate soccer players over the course of one pre-season period. We used these measures to both evaluate the chronic fatigue imposed by pre-season training and assess the athletes' daily readiness to play, evaluating the merit of these measures to reflect both physical and mental training-induced fatigue.

Subjects

Three female collegiate soccer players (characterized in Table 1) participated in this case study. All players competed for the same school in the NCAA Division 1, with a minimum of 2.5 years of collegiate playing experience and a minimum of two years playing as a starter. All subjects were highly trained and injury-free (an injury that caused them to miss training) for at least three months prior to at the start of training camp (the duration of off-season training). With the exception of Subject 2, who missed two training sessions during the last week of training due to injury, all subjects participated in all training sessions through the pre-season period. All subjects agreed to study protocol prior to beginning.

Table 1. Subject Characteristics

	Subject 1	Subject 2	Subject 3
Age (yrs.)	21	21	20
Body mass (kg)	58.5	72.5	72.5
Position	Outside defender	Central defender	Center forward
Yrs. participating in soccer	16	15	17
Yrs. soccer-specific training (total)	9	8	10
Soccer-specific endurance test	21:00 (min:sec)	25:00 (min:sec)	26:55 (min:sec)
Yo-Yo intermittent recovery level 1	50	32	34

Note: Team fitness standards, as imposed by the head coach, were <27:00 for the soccer-specific endurance test, and ≥30 for the Yo-Yo Intermittent Endurance Test, Level 1. If players did not reach these standards, they were to retake the tests before they could dress for a game.

Training Log

We monitored sport-specific training for the 2.5-week pre-season period of the 2015 NCAA soccer season. This pre-season period spanned 17 days, from the beginning of the pre-season training camp (August 5) to the season-opening competitive game (August 21). Training included on-field sessions with the sport coaching staff and weight room session with the strength and conditioning coaching staff. During this pre-season period, there are no NCAA restrictions on training hours per week, including on-field, off-field, or weight room sessions. The sport coaches and strength coach controlled all training variables; we did not intervene in any aspect of prescribed training. The following variables regarding each training session were recorded: length in minutes (encompassing both the on-field and weight training portions of the session, since weight training occurred immediately after on-field training), time of day, temperature, humidity, and heat index.

Calculations of Training Load

We calculated training load using session-RPE (sRPE). As per Foster et al., each player's rating of perceived exertion (RPE) was recorded on a 10-point scale (Figure 1) 30-60 minutes after each training session[7]. Whole integrals or scale intervals of 0.5 were allowed. Players were instructed to provide global RPE, answering the question "How was your workout?" for the whole training session, including both on-field and weight room sessions. sRPE was calculated by multiplying RPE by the length of the training session in minutes[7]. To calculate the cumulative TL for each day, including both the morning and afternoon sessions, we calculated the sum of sRPE for each session.

Figure 1. 10-point RPE Scale (as per Foster et al.)[7]

Rating	Descriptor
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal

Measurements of Subjective Fatigue

A subjective fatigue questionnaire (Figure 2) was administered to each player at least 15 minutes before the first training session of each day, after the player had been awake and ambulatory for at least 20 minutes. Adapted from Buchheit et al.[9] and McLean et al.[10], this questionnaire was designed to assess global fatigue using a 5-point Likert Scale. For each of the seven categories, the descriptor with a score of 5 indicates the highest response for readiness to compete, whereas the descriptor with a score of 1 indicates the lowest response.

Figure 2. Subjective Fatigue Questionnaire

1	2	3	4	5
Hydration Status				
1	2	3	4	5
Very dehydrated		Could drink more		Very well hydrated
Caffeine Intake				
1	2	3	4	5
Much less than usual		Average		Much more than usual
Soreness				
1	2	3	4	5
It hurts to move		Some light soreness		Feeling fresh!
Readiness to Play				
1	2	3	4	5
Need more time, heavy legs		A little tired but can push through		Put me in, Coach. Rested and ready
Mood				
1	2	3	4	5
Horrible, don't feel like doing anything		Normal, generally good		Great, happy, motivated, hopeful!
Stress				
1	2	3	4	5
Super stressed, cannot focus		Some stress but able to focus		Life's a beach. Clear mind, no stress
Sleep Quality				
1	2	3	4	5
Terrible, short and restless		Average, could have been longer		Very restful, long, like a baby

Players were instructed to provide an honest answer according to how they felt at the moment they were taking the questionnaire, without factoring in past or future training demands. This was emphasized in order to eliminate confounding effects if players anticipated physically demanding training sessions. Items 1 and 2 on the questionnaire were excluded from correlation comparisons due to their limited translation to training-induced fatigue.

Categorization of Personality Types

In order to control for differences in personality type in how they relate to perceptual TL and subjective fatigue, we administered the Preference for and Tolerance of the Intensity of Exercise Questionnaire (PRETIE-Q). The PRETIE-Q is a 16-item questionnaire as outlined by Ekkekakis et al.[11] that assesses preference for and tolerance for high-intensity exercise. The PRETIE-Q has been used in college-aged females to predict the intensity of self-selected exercise (preference), as well as the time of exercise beyond the ventilatory threshold (tolerance)[12]. Subjects were instructed to provide honest answers regarding their own personal exercise habits, not their habits during training or competition. As these subjects are all competitive soccer players, it is likely they approach high-intensity, structured training in a similar manner, whereas their personal exercise habits and attitudes may differ.

Statistical Analysis

Using Microsoft Excel, we ran correlation statistics (Pearson product moment correlation coefficients and r^2 values) to compare training load (sRPE) with subjective fatigue (questionnaire responses) on both the day of the training load (fatigue before training: prospective) and the day following the training load (fatigue the next day after training: retrospective). We compared TL with the following variables from the questionnaire: mean score for questions 3-7, sum of the scores for questions 3-7 (with a maximum of 25 indicating full readiness to play), subjective physical fatigue (sum of questions 3 and 4), subjective mental fatigue (sum of questions 5 and 6), and questions 3-6 individually. Based on Hopkins' interpretation, we considered an r value of >0.5 to be large, 0.5-0.3 to be moderate, 0.3-0.1 to be small, and <0.1 to be trivial[13]. For questionnaire data, we interpreted a difference of ±1 SD from the mean to be meaningful.

Results

Quantification of Training Load

We found fluctuations in TL for the entire preseason period until the first competitive game (Figure 3).

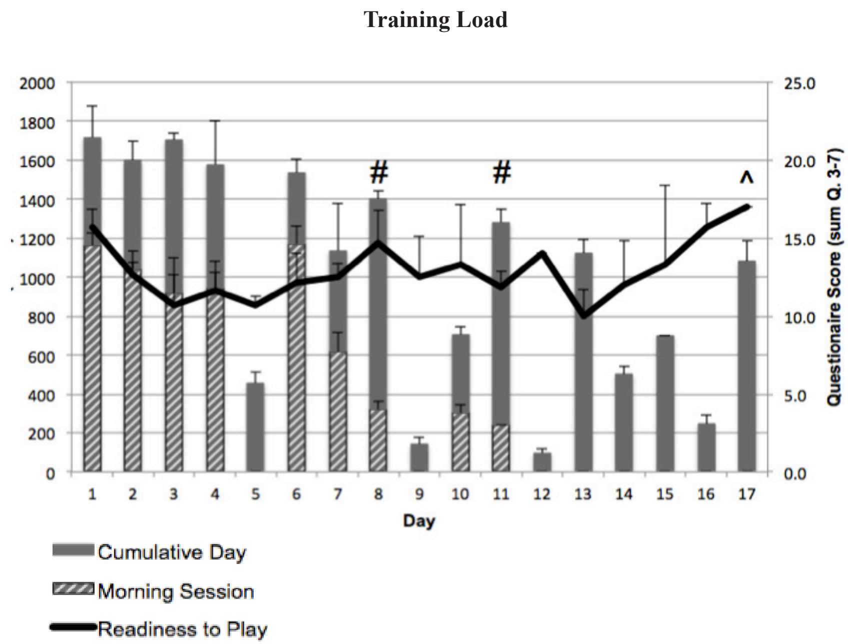

Figure 3. Training load and daily readiness to play (questionnaire score: sum of questions 3-7) over the course of the pre-season period (17 days). If there were two training sessions per day, the first session is shown as morning session and the afternoon session is included in the cumulative day TL. If there was only one training session per day, data are shown as cumulative day TL, regardless of the time of day that session was held. # indicates day of a pre-season exhibition game. ^indicates the first competitive game. n=3, data are presented as mean ± SD.

Relationship Between TL and Subjective Fatigue Variables

We found trivial to moderate correlations in all of the following comparisons: TL and retrospective fatigue variables (r≤0.42, Figure 4), TL and prospective fatigue variables (r≤0.32, Figure 5), and TL and environmental variables (r≤0.37, Table 2). Differences in TL accounted for no more than 18% of the variation in any variable of fatigue status the following day. Differences in any variable of fatigue status before training accounted for no more than 10% of the variation in TL for that day. Environmental variables, namely temperature and heat index, account for no more than 14% of the variance in TL for that day.

Figure 4. Correlation Summary: TL vs. Next-day fatigue variable. n=3, ❍=subject 1, ❑=subject 2, ●=subject 3, ✕=mean of absolute value for correlation coefficient. Absolute values were taken to calculate means in order to eliminate directionality and assess the magnitude of the correlation.

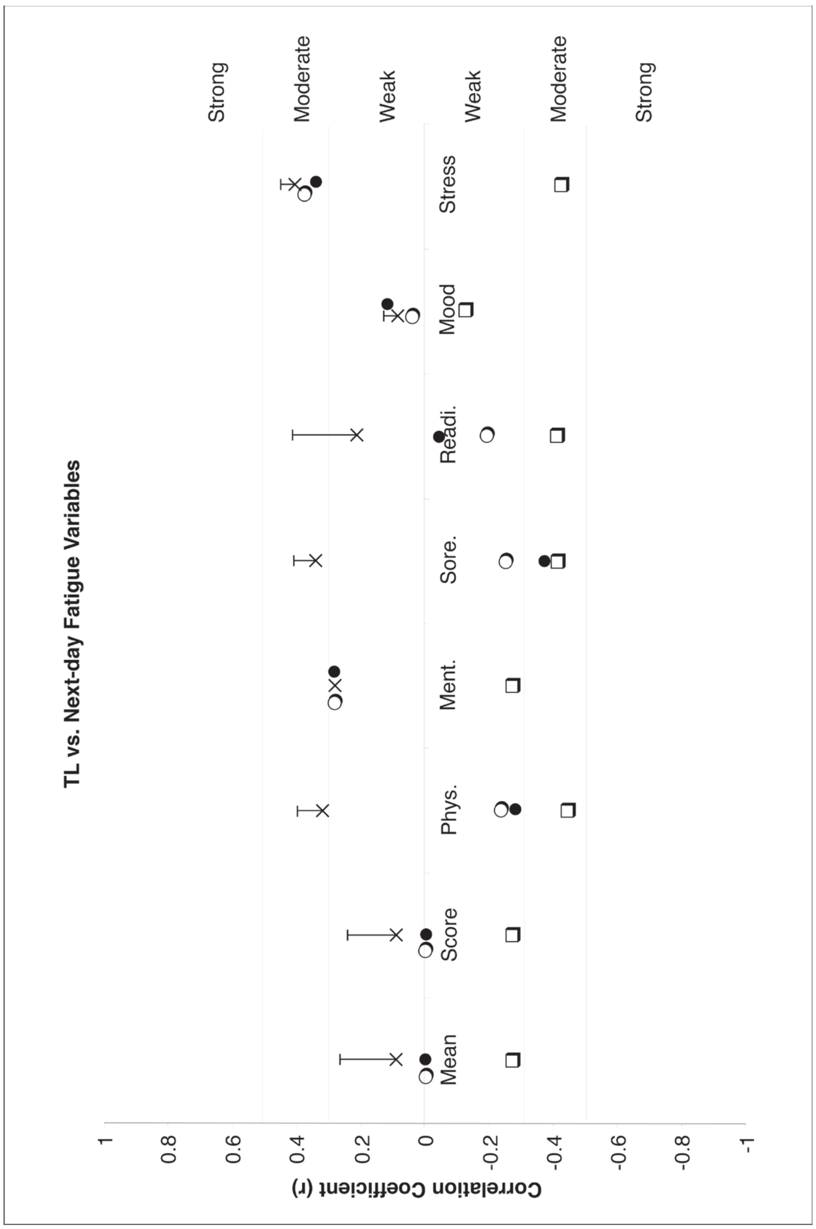

Figure 5. Correlation Summary: Pre-training fatigue variables vs. same-day TL. n=3, ❍=subject 1, ❑=subject 2, ●=subject 3, ✕=mean of absolute values for correlation coefficient. Absolute values were taken to calculate means in order to eliminate directionality and assess the magnitude of the correlation.

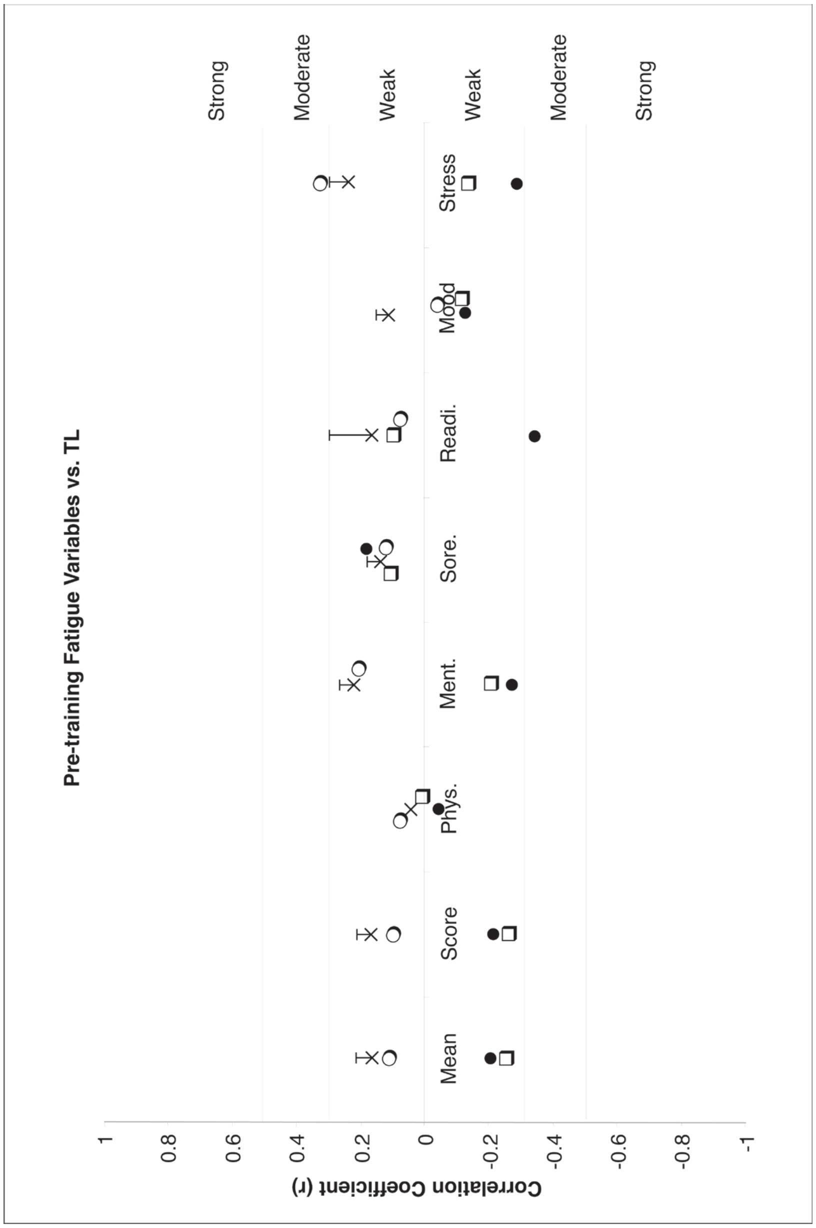

Table 2. Correlation Summary: TL vs. Environmental Variables [r (r^2)].

Subject	Temperature	Humidity	Heat Index
1	0.33 (0.11)	0.06 (0.00)	0.37 (0.14)
2	0.30 (0.09)	0.07 (0.00)	0.33 (0.11)
3	0.08 (0.01)	0.22 (0.05)	0.12 (0.01)

Note: Environmental variables were recorded as the average for the day of the training session(s).

Characterization of Personality Types

Subject 3 displayed a meaningful difference from the mean in preference for high-intensity exercise (Table 3), whereas Subjects 1 and 2 were similar. Subject 1 displayed a meaningful difference from the mean in tolerance for high-intensity exercise, whereas Subjects 2 and 3 were similar.

Table 3. Preference and Tolerance for Exercise Intensity [PRETIE-Q Score (percentile rank, based on college-aged females) [12]]

Subject	Preference	Tolerance
1	34 (94th)	33 (96th)*
2	38 (99th)	28 (80th)
3	26 (62nd)*	30 (88th)
Mean	**32.67**	**30.33**
SD	**6.11**	**2.52**

*Indicates meaningful difference from mean (± 1 or more SD).

Discussion

We assessed the relationship between perceptual TL (sRPE) and subjective fatigue (questionnaire responses) as a means to monitor training-induced stress in three collegiate soccer athletes throughout the pre-competitive period. Mean TL varied from 140-1715 AU over the course of the pre-season period, and this variation was expected. This is comparable to others that have examined RPE-based TL in field sports: Buchheit et al.[9] found mean sRPE values between 135-1904 AU during a pre-season camp in Aussie Rules Football players, and Impellizzeri et al.[4], found mean sRPE values between 180-848 AU in college-age soccer players over seven weeks of the competitive season. However, normative data or other studies examining the same outcomes are not available for sRPE-based TL in a college soccer pre-season, so it is hard to assess how our pre-season demand compares to other similar teams during the same time of year.

While sRPE has been validated against heart rate-based methods for TL in a single session[4,5,7,9], we did not take the objective measures needed to validate our calculation of cumulative sRPE for the whole day (sum of sRPE for both sessions each day). This calculation is assuming that the morning session does not affect the physiological variables and thus sRPE for the second session, but it is likely that the morning session, including environmental differences in the time of day, can potentiate the physiological responses to training in the second session, and thus invalidate the relationship with sRPE. This remains a limitation to our case study.

Is subjective TL related to overall fatigue status?

As we found TL fluctuated over the course of the pre-season, it is reasonable to expect similar changes in fatigue status. However, we did not find meaningful correlations ($r=0.00$-0.27) between subjective TL (as assessed by sRPE) and overall fatigue status (as assessed by the questionnaire score or mean score, either prospectively or retrospectively). This is in contrast to Buchheit et al.[9], who found that changes in TL had a significant ($p<0.05$) effect on next-day overall wellness scores, and McLean et al.[10], who found a similar 5-item questionnaire sensitive to fatigue-induced changes in performance following a match. Our findings could be due to one of two reasons: 1) sRPE as a method of monitoring TL did not reflect physical demands of training, or 2) our questionnaire was not valid and not sensitive to changes in fatigue status to find meaningful changes. It is likely the latter, as different authors have shown sRPE to correlate to objective heart rate-based measurements[4,5,7], thus making it a valid measure for aerobic-based activities.

A limitation of our case study was the subjective nature of our responses: due to limited resources, we did not take any objective measures of internal TL (i.e. heart rate), objective measures of fatigue status (i.e. performance tests) or measures of external TL (i.e. distance ran). All of these would have given physiological insight into the validation of sRPE and the questionnaire used in our case study. Had we been able to validate our measures, we could definitively attribute the weakness of our correlations to one variable. Additionally, although it is likely that greater levels of pre-training fatigue cause an increase in RPE for that day's training session, we did not control training duration or intensity. It is likely that variations in these training variables masked any differences to RPE caused by pre-existing fatigue. Measuring RPE for a specific, consistent exercise task (such as a uniform warm-up) would have given more insight into the effects of pre-training fatigue.

Is TL better related to individual fatigue variables?

Though we did not find strong or moderate correlations between TL and overall fatigue status, or TL and prospective fatigue variables, we examined trends between the individual physical and mental variables of retrospective fatigue. The lack of correlation found between TL and overall fatigue could be due to the opposing relationships between TL and physical and mental fatigue, respectively. As was expected, TL had negative correlations with next-day physical readiness for all subjects, in that as TL increased, physical readiness decreased, indicating higher levels of physical fatigue. However, this correlation was small for Subjects 1 (r= -0.24) and Subject 3 (r=-0.27) and moderate for Subject 3 only (r=-0.44), accounting for 6%, 7%, and 19% of the variance, respectively. Conversely, TL Subjects 1 and 3 had positive correlations (r=0.29-0.30) with mental fatigue, indicating the greater the TL, the greater the mental score (lower stress and better mood). Contrary to our expected results, one reason for this relationship may be that stress is decreased and mood is elevated after completing a demanding day of training. Along the same avenue, mental readiness to play may relate more closely to training load on that day, as mood may decrease and stress may increase before a difficult session or competition. However, we did not make that comparison, as subjects completed the questionnaire without anticipating future training.

In addition to physical and mental fatigue, we found small to moderate correlations between TL and individual retrospective fatigue variables. This is similar to Buchheit et al.[9], who found small to moderate correlations between TL and respective responses for fatigue, sleep, soreness, stress, and mood respectively, despite large correlations between overall wellness and performance. While TL accounted for 6%-19%

change in the next-day physical variables, it was more closely related to soreness (r=0.34±0.9, accounting for 6%-17% of the variance), than readiness (r=0.22±0.18, accounting for 0%-17% of the variance). This is in line with Buchheit et al, who found moderate correlations (r=0.3) between TL and soreness. While TL accounted for 7%-9% of the variance in mental fatigue, it was more closely related to stress (r=0.38±0.04, accounting for 12%-18% of the variance) than mood (r=0.09±0.04, accounting for 0%-1% of the variance). Notably, this relationship was reversed in Subject 2 compared to Subjects 1 and 3, further supporting individual differences in subjective training response. This is also related to Buchheit et al, who found small correlations (r<0.3) between TL and mood and soreness, respectively. While they displayed differences, these correlations are too weak to find meaningful relationships, indicating the need for more specific and training-sensitive measures of subjective fatigue.

Does personality play a role in TL and the fatigue response?

Because our measures of TL and fatigue were subjective and thus at high risk for inter-individual differences, we assessed personality differences in preference for high-intensity exercise and exercise tolerance using the PRETIE-Q questionnaire. Based on normative data for college-age females from Ekkekakis et al.[12], Subjects 1 and 2 were in the upper 6% of individuals for exercise preference, substantially higher than Subject 3, indicating they prefer high-intensity exercise over low-intensity. All subjects were in the upper 20% of individuals for exercise tolerance, indicating they can tolerate high-intensity exercise to a greater degree than average individuals. Because they are college athletes playing a high-intensity aerobic-based sport, this is expected. Only Subject 1 was substantially higher than Subjects 2 and 3 in this category, indicating higher tolerance for high intensity exercise. This could indicate lower RPE for the same training session as Subject 2 and 3. Additionally, differences in playing position (Table 1) could indicate different external TL, and thus different internal TL, for each subject in the same training session or game. This speaks for the need to individualize training response, like Manzi et al.'s[2] use of individualized training impulse throughout the soccer pre-season that accounted for differences in aerobic fitness and external load.

Implications for performance

Monitoring TL and fatigue is only important if the practitioner can assess the point at which an increase in these measures becomes physiologically relevant to changes in performance. Had we found large correlations between TL and fatigue status, we still could not definitively say that these changes are meaningful until we could measure a decrease in performance. Buchheit et al.[9] examined soccer-specific performance (high speed running total distance covered) on standardized training drills and the Yo-Yo Intermittent Recovery Level 2 test, and found a large correlation between these measures and mean wellness score. This suggests that wellness score can predict performance, which has important implications for exercise prescription. Adjustments in training programming can be crucial to competitive success. In high-level sport such as intercollegiate soccer, even small decrements in performance can have large effects on the outcome of competition.

Conclusion And Practical Application

Despite the relationships between TL and fatigue variables in preexisting literature, we cannot draw definitive conclusion from our data because the effects were small to moderate. While the gold standard of measuring TL remains unknown, sRPE may be a feasible method if combined with valid and objective measures of fatigue status and performance. Additionally, it may be warranted to examine aspects of physical and mental fatigue separately in addition to overall fatigue, while accounting for individual differences.

Endnotes

1. Borresen J, Lambert MI. The quantification of training load, the training response, and the effect on performance. *Sports Medicine*. 2009;39(9):779.

2. Manzi V, Bovenzi A, Impellizzeri MF, Carminati I, Castagna C. Individual training-load and aerobic-fitness variables in premiership soccer players during the precompetitive season. *Journal of Strength and Conditioning Research*. 2013;27(3):631.

3. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Medicine*. 2014;44:S139.

4. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-based training load in soccer. *Medicine and Science in Sports and Exercise*. 2004;36(6):1042.

5. Borresen J, Lambert MI. Quantifying training load: A comparison of subjective and objective methods. *International Journal of Sports Physiology and Performance*. 2008;3:16.

6. Taylor K, Chapman DW, Cronin JB, Newton MJ, Gill N. Fatigue monitoring in high performance sport: A survey of current trends. *Journal of Australian Strength and Conditioning*. 2012;20(1):12.

7. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research*. 2001;15(1).

8. Abbiss CR, Laursen PB. Models to explain fatigue during prolonged endurance cycling. *Sports Medicine*. 2005;35(10):865.

9. Buchheit M, Racinais S, Bilsborough JC, et al. Monitoring fitness, fatigue, and running performance during a pre-season training camp in elite football players. *Journal of Science and Medicine in Sport*. 2013;16:550.

10. McLean BD, Coutts AJ, Kelly V, McGuigan MR, Cormack SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance*. 2010;5.

11. Ekkekakis P, Hall EE, Petruzzello SJ. Some like it vigorous: Measuring individual differences in the preference for and tolerance of exercise intensity. *Journal of Sport and Exercise Psychology*. 2005;27.

12. Ekkekakis P, Thome J, Petruzzello SJ, Hall EE. The preference for and tolerance of the intensity of exercise questionnaire: A psychometric evaluation among college women. *Journal of Sport Sciences*. 2008;26(5).

13. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*. 2009;41(1).