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A Comparison of Methods to Quantify the In-Season Training Load of Professional Soccer Players

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Purpose: To compare various measures of training load (TL) derived from physiological (heart rate [HR]), perceptual (rating of perceived exertion [RPE]), and physical (global positioning system [GPS] and accelerometer) data during in-season field-based training for professional soccer. ***Methods:*** Fifteen professional male soccer players (age 24.9 ± 5.4 y, body mass 77.6 ± 7.5 kg, height 181.1 ± 6.9 cm) were assessed in-season across 97 individual training sessions. Measures of external TL (total distance [TD], the volume of low-speed activity [LSA; <14.4 km/h], high-speed running [HSR; >14.4 km/h], very high-speed running [VHSR; >19.8 km/h], and player load), HR and session-RPE (sRPE) scores were recorded. Internal TL scores (HR-based and sRPE-based) were calculated, and their relationships with measures of external TL were quantified using Pearson product–moment correlations. ***Results:*** Physical measures of TD, LSA volume, and player load provided large, significant (r = .71–.84; P < .01) correlations with the HR-based and sRPE-based methods. Volume of HSR and VHSR provided moderate to large, significant (r = .40–.67; P < .01) correlations with measures of internal TL. ***Conclusions:*** While the volume of HSR and VHSR provided significant relationships with internal TL, physical-performance measures of TD, LSA volume, and player load appear to be more acceptable indicators of external TL, due to the greater magnitude of their correlations with measures of internal TL.

Keywords: motion analysis, exercise training, sport

To examine whether soccer players are meeting, or indeed exceeding, training requirements, it is vital to monitor their individual training load (TL) throughout the competitive season. This may also allow coaching staff to examine the response of players to a quantified TL and therefore provide information regarding the efficacy of the training dose. The most common methods currently used to quantify training intensity and TL in field sports involve analyzing players' heart rate (HR) and rating of perceived exertion (RPE).[1] In addition, recent advances in methods to quantify the movement demands of athletes have resulted in various external measures to estimate exercise intensity and TL using physical-movement data.[2] As a consequence, measures of TL are categorized in accordance with the method used to quantify intensity; such categories include internal TL (HR-based and RPE-based) and external TL (movement-based).

Internal TL requires quantification of the physiological stress imposed on an athlete by exercise.[3] It may therefore be viewed as an athlete's response to a physical stimulus (external TL). The outcome of training is the consequence of both internal and external stimuli, which is well described in the conceptual model by Impellizzeri et al.[3] However, it must be acknowledged that internal TL and external TL are different constructs. To comprehensively monitor training, it is important to quantify both of these measures and assess the relationships between them.[4] This will provide coaching and conditioning staff with valuable information detailing whether the desired training stimulus has been achieved (ie, external TL) and how athletes are responding to this training (ie, internal TL). However, the relationships between these constructs in professional soccer players are not fully understood.

The use of HR monitoring is common in professional soccer, providing a noninvasive measure of players' physiological function across a training session. Banister's[5] HR-based training impulse (Banister's TRIMP) and Edwards'[6] summated-HR-zones (Edwards' TRIMP) equations have recently been used to estimate internal TL in soccer and other intermittent activities.[1,7,8] However, due to an increased contribution of anaerobic metabolism to team sports, the validity of HR measures to monitor work rate in soccer has been questioned.[9]

The session-RPE (sRPE) method proposed by Foster et al[10] is currently the only subjective measure of TL to have been widely adopted in team sports.[7] It is suggested to be inclusive of factors such as physical work rate, injury, illness, weather conditions, match scheduling, and psychological status.[8] Previous investigations have reported moderate to large correlations between the sRPE method and HR-based Banister's TRIMP and Edwards' TRIMP during intermittent activity (r = .50–.84 and

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.54–.85, respectively), indicating that the sRPE method is a good practical measure of internal TL.[1,4,7,8] While it has been suggested that intersubject comparisons of sRPE may be inaccurate,[11] the subjective range of intensity (from minimal to maximal) is known to be equal between individuals.[12] Consequently, factors including fitness characteristics and fatigue states may induce intersubject variations in sRPE scores, and this method may be an acceptable measure of internal TL in team sports.[1]

External TL can be derived from measures of a player's movement during exercise. Recent developments in global positioning system (GPS) and accelerometer technology have resulted in portable methods of performing such analyses. These technologies are becoming increasingly popular for team-sport monitoring.[13,14] GPS-based measures of total distance (TD), average running speed, and distance covered at speeds greater than 14.4 km/h and 20 km/h have been used to quantify physical performance in intermittent team sports such as Australian football.[2,4] However, research suggests that the reliability of GPS-measured distance is decreased at high speeds.[2] Triaxial accelerometers have also been used to quantify the external TL of professional soccer players, using the total-body-load equation.[15] However, due to a poor relationship with the sRPE method, this measure was suggested to be an invalid indicator of external TL in soccer.[15] In contrast, the accelerometer-based external TL of Australian football players has been quantified via the player-load equation, which showed a large correlation (r = .83) with the sRPE method.[4] The accelerometers used to calculate player load have exhibited acceptable interdevice reliability during high-intensity Australian football activity[13] and validity when quantifying collisions in rugby league.[16] However, the use of GPS data and the player-load equation to quantify external TL during professional soccer is yet to be comprehensively examined.

Therefore, the purpose of this study was to compare the sRPE method and 2 popular HR-based methods (Banister's TRIMP and Edwards' TRIMP) against measurements of player movements and accumulated accelerations (player load) to assess the use of GPS and accelerometer technologies in estimating external TL in professional soccer players.

Methods

Subjects

Fifteen male soccer players (age 24.9 ± 5.4 y, body mass 77.6 ± 7.5 kg, height 181.1 ± 6.9 cm) were recruited from a professional team competing in the Australian A-League. The subject group was composed of attacking, midfield, and defensive players. For inclusion in the study, players were required to be currently contracted to the applicable Australian A-League squad, be willing volunteers, and be injury free. The study and its methods were approved by the institutional human ethics committee and supported by coaching staff. All subjects were provided with information detailing subject requirements and the purpose of the study and screened for medical contraindications, and all provided informed consent.

Study Design

Before the commencement of training-data collection, subjects completed a Yo-Yo Intermittent Recovery Test, Level 1 to determine maximal HR (HR_{max}) at the point of self-selected exhaustion, as per established methods.[17] Polar Team[2] Pro (Polar Electro, Kempele, Finland) HR monitors were worn by all players around the torso, level with the xiphoid process, during the test. Players were also provided with HR monitors to take home and were instructed to wear the device for 2 minutes while lying supine on waking to quantify resting HR (HR_{rest}).

Data were collected across 29 field-based training sessions during the 2010–11 A-League competition season. Subjects encompassing attacking, midfield, and defensive roles (n = 3–5 per session) were monitored across 6.5 ± 3.0 team training sessions each, resulting in 97 individual sessions being recorded. Subjects wore a MinimaxX 2.0 GPS device (Firmware version 6.59, Catapult Innovations, Scoresby, Australia) fitted in a small pocket of an undergarment located posteriorly between the scapulae, as well as an HR monitor. All players wore the same monitoring devices each time they were assessed and recorded sRPE scores posttraining.

Field-Based Training

Field-based training programs were designed entirely by coaching staff to elicit technical, tactical, and physiological responses in the playing group. The aims of training varied in accordance with the team's periodized training plan and residual player fatigue. All field players completed training under the same conditions. Table 1 details the activities performed during a typical training session, which was usually 60 to 90 minutes in duration.

Methodology

Physiological training intensity was monitored continuously throughout each training session using a telemetric HR monitor recording a data point every 5 seconds.

Table 1 Structure of a Typical In-Season Field-Based Training Session for Professional Soccer

Activity	Description
General warm-up	Slow jog, static/dynamic stretches
Specific warm-up	Shuttle runs, small passing, and dribbling drills
Technical development	Longer passing/shooting drills and agility runs
Tactical/technical development	Small-sided games (5 v 5/4 v 4), full-field match play, and set plays
Cooldown	Walk, static/dynamic stretching, core strengthening

Subjects' HR data were stored in a MinimaxX 2.0 GPS device worn by the players and downloaded into Logan Plus software after each training session for analysis. These HR data were subsequently analyzed to quantify internal TL via Banister's[5] TRIMP and Edwards'[6] TRIMP equations:

$$\text{Banister's TRIMP: [Duration (min)]}(HR_{ex} - HR_{rest})/(HR_{max} - HR_{rest})0.64e^{1.92x}$$

where HR_{ex} = average HR during exercise, HR_{rest} = HR at rest, HR_{max} = predetermined maximal HR, $e = 2.712$, and $x = (HR_{ex} - HR_{rest})/(HR_{max} - HR_{rest})$.

$$\text{Edwards' TRIMP: duration in zone } 1 \cdot 1 + \text{duration in zone } 2 \cdot 2 + \text{duration in zone } 3 \cdot 3 + \text{duration in zone } 4 \cdot 4 + \text{duration in zone } 5 \cdot 5$$

where Zone 1 = 50% to 60% HR_{max}, Zone 2 = 60% to 70% HR_{max}, Zone 3 = 70% to 80% HR_{max}, Zone 4 = 80% to 90% HR_{max} and Zone 5 = 90% to 100% HR_{max}.

Perceptual training intensity was quantified using Borg's Category Ratio-10 RPE scale (Table 2). Before the commencement of the study, players were familiarized with the scale and provided with standardized anchoring procedures. The sRPE method[18] was used to estimate internal TL, whereby the sRPE score provided by players was multiplied by training duration (min) to estimate internal TL in accordance with previous methods.[10] The sRPE scores were recorded 30 minutes after the conclusion of training to eliminate bias resulting from the final phase of exercise, as per established methods.[18]

External training intensity and load were determined via positional GPS and accelerometer data. The GPS devices used in the current study did not delineate forward, backward, or lateral directions, with all movement being considered universal. Average speed (m/min) across each session was recorded to quantify external training intensity. The TD covered (m) and the volume of low-speed activity (LSA; <14.4 km/h), high-speed running (HSR; >14.4 km/h), and very-high-speed running (VHSR; >19.8 km/h) were recorded in meters and seconds to calculate external TL. These locomotor categories are consistent with recent time–motion analysis of soccer.[19–21] In addition, data obtained from a triaxial accelerometer (Kionix: KXP94) in the GPS device were used to classify external TL using the player-load equation. This was calculated by Logan Plus software via the following equation:

$$(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2$$

where a_y = anteroposterior acceleration, a_x = mediolateral acceleration, and a_z = vertical acceleration.

Individual subjects' training data were eliminated from analysis if they failed to complete the training session due to injury, GPS data were considered erroneous (a horizontal dilution of position greater than 5 was recorded or the number of satellites available was less than 5), or HR signal was interrupted or lost. The exclusion criteria resulted in a total of 97 individual sessions being selected for analysis.

Table 2 The Modified Borg Category Ratio-10 Rating of Perceived Exertion Scale[18]

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

Statistical Analyses

The mean and SD for each variable were determined to quantify the training session demands. Relationships between the various measures of internal TL and external TL were analyzed using Pearson product–moment correlations, and the 95% confidence intervals around the correlation coefficient were calculated using a custom spreadsheet designed for this purpose.[22] These relationships were determined between internal TL and external TL measures for each training session completed by individual players. As per Cohen,[23] a correlation coefficient value of .10 or less was considered trivial, .11 to .30 small, .31 to .50 moderate, and greater than .51 large. Statistical analyses were performed using the Statistics Package for the Social Sciences (version 18.0, SPSS Inc, Chicago, IL). Statistical significance was set at $P < .05$.

Results

The mean physiological intensity of training sessions was 67.3% ± 4.8% of individual HR_{max}. Mean internal TL scores derived from Banister's TRIMP and Edwards' TRIMP were 77.5 ± 25.4 arbitrary units (AU; range 20.6–167.9 AU) and 169.2 ± 54.0 AU (range 50.8–367.5 AU), respectively. Perceptual intensity of training sessions corresponded to mean sRPE scores of 3.9 ± 1.5 AU (range 1–8 AU). Mean internal TL calculated using the sRPE method was 297 ± 159 AU (range 38–936 AU).

Figure 1 displays the intensity and duration of field-based training in the form of internal TL. Fluctuations in TL are clearly evident across the 29 training sessions assessed. Large relationships were found between measures of internal TL. These ranged from $r = .73$ to $r = .77$ (Figure 2).

The mean external intensity of training sessions corresponded to an average speed of 61 ± 9 m/min (range 43–83 m/min). Measures of external TL, derived from GPS data, are further described in Table 3.

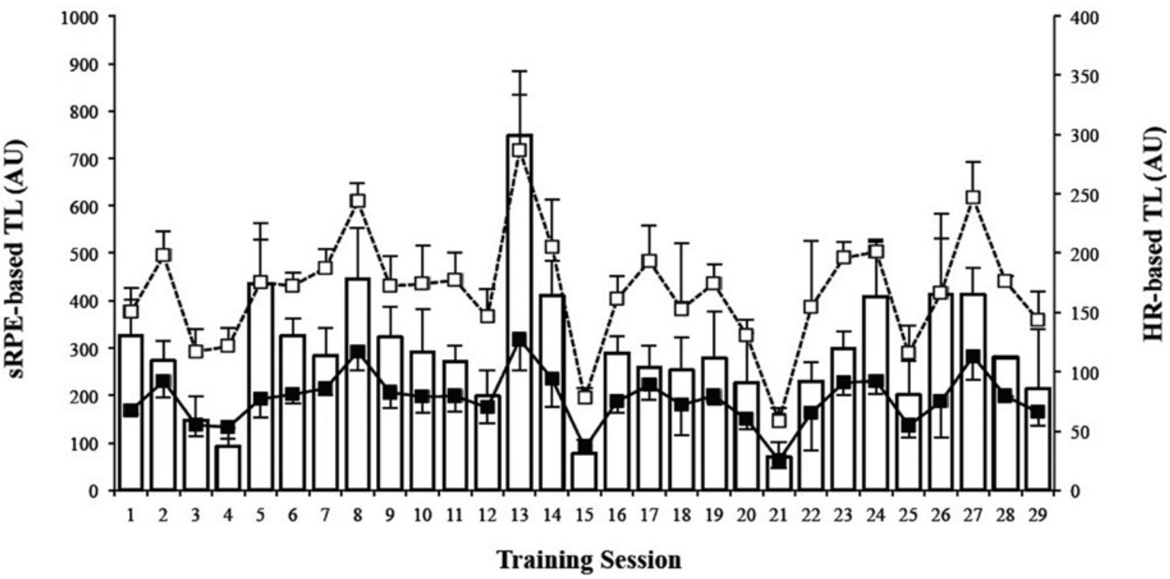

Figure 1 — Internal training load (TL) of professional soccer players (N = 15) during in-season field-training sessions, mean ± SD. AU indicates arbitrary units; white bars, session rating of perceived exertion (sRPE) TL; black boxes on solid line graph, Banister's training impulse (TRIMP); white boxes on dotted line graph, Edwards' TRIMP.

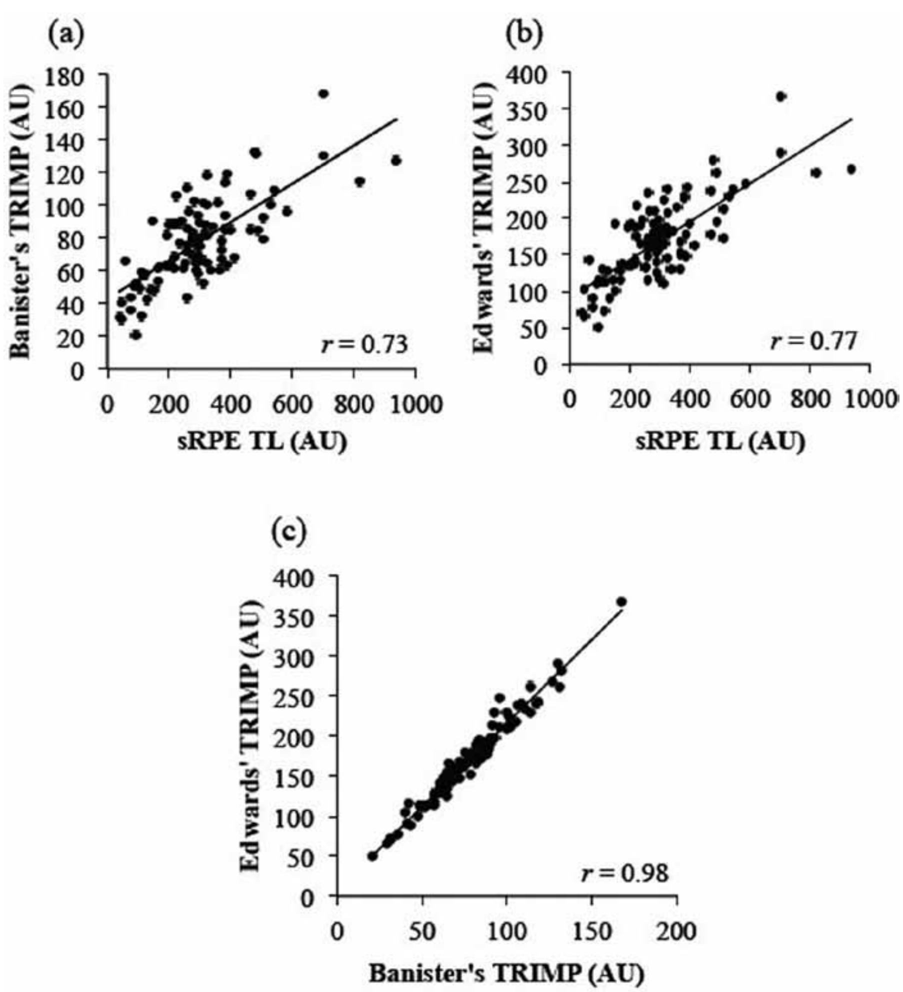

Figure 2 — Correlations between (a) session rating of perceived exertion (sRPE) training load (TL) and Banister's training impulse (TRIMP), (b) sRPE TL and Edwards' TRIMP, and (c) Banister's TRIMP and Edwards' TRIMP. AU indicates arbitrary units.

Table 3 Global-Positioning-System-Based Measures of Field Players' Running Performance During Training Sessions (N = 97)

	Absolute Values		% of Training Total	
Variable	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**
Training distances (m)				
total distance	4467 ± 1296	2143–9540	—	—
low-speed activity	3923 ± 1101	2014–8237	88.8 ± 3.8	76.7–95.1
high-speed running	544 ± 255	106–1343	12.0 ± 3.8	4.9–23.3
very-high-speed running	132 ± 101	7–541	2.8 ± 1.9	0.2–8.8
Training durations (s)				
total duration	4386 ± 1042	2294–7023	—	—
low-speed activity	4254 ± 1007	2165–6806	97.0 ± 1.2	93.4–99.2
high-speed running	109 ± 49	22–264	2.5 ± 1.0	0.7–5.5
very-high-speed running	21 ± 15	1–79	0.5 ± 0.4	0.0–1.6
Average speed (m/min)	61 ± 9	43–83	—	—

Table 4 Correlation Coefficients (95% Confidence Intervals) Between Measures of Internal and External Training Load

	Internal Training Load		
External training load	**sRPE training load**	**Banister's training impulse**	**Edwards' training impulse**
Total distance	.80 (.72–.86)	.73 (.62–.81)	.78 (.68–.84)
Low-speed activity distance	.80 (.71–.86)	.72 (.61–.81)	.77 (.67–.84)
Low-speed activity time	.78 (.69–.85)	.71 (.64–.84)	.77 (.68–.84)
High-speed running distance	.65 (.51–.75)	.58 (.43–.70)	.62 (.48–.73)
High-speed running time	.67 (.54–.77)	.58 (.44–.70)	.63 (.50–.74)
Very-high-speed-running distance	.43 (.26–.58)	.40 (.22–.55)	.41 (.23–.57)
Very-high-speed-running time	.46 (.29–.60)	.40 (.22–.56)	.42 (.24–.57)
Player load	.84 (.77–.89)	.73 (.62–.81)	.80 (.71–.86)

Similar to internal TL, large variations were observed across all GPS-based external TL measures. The mean accelerometer-based player load in the current study was 558 ± 158 AU, which also demonstrated a large range (278–1053 AU).

The means and 95% confidence intervals of the correlation coefficients for the measures of TL are shown in Table 4. All correlations between measures of internal TL showed statistical significance ($P < .01$). Measures of internal TL displayed statistically significant correlations ($P < .01$) with all measures of external TL, including TD; volume of LSA, HSR, and VHSR; and player load. Furthermore, TD demonstrated a large relationship with player load ($r = .93$).

Discussion

All measures of TL in the current study were shown to fluctuate greatly across the training sessions assessed (Figure 1), reflecting the team's periodized training schedule. In agreement with previous research,[1,7,8] the traditional measures of TL (Banister's TRIMP, Edwards' TRIMP, and sRPE methods) demonstrated large correlations with each other in the current study (Figure 2). However, the novel findings of the current study are related to the measures of external TL. Despite a recent increase in the use of GPS and accelerometer technology for field-sport monitoring,[14] the ability of these physical data to quantify external TL in professional soccer remains unclear. The measures of external TL derived from GPS and accelerometer technologies demonstrated moderate to large relationships with the aforementioned internal TL measures (Table 4). However, it is important to recognize that internal TL and external TL are derived from inherently different measures of intensity. Nonetheless, the relationships between these forms of TL provide pertinent information for sport scientists and coaches using the various measures. The current findings suggest that these GPS and accelerometer technologies may provide practical means to quantify the TL of professional soccer players during field-based training.

While the microtechnologies used in the current study allow coaching and conditioning staff to monitor players during training, comparisons with match play are difficult, as current regulations prohibit players from wearing such devices during Fédération Internationale de Football Association–sanctioned matches.

The volumes of HSR and VHSR (in meters and seconds) have been suggested as important performance measures in soccer match play and indeed may differentiate between elite- and nonelite-level players.[17,19] To our knowledge, no data have been published that assess these performance measures or the volume of LSA as indicators of external TL in soccer. Results of the current investigation showed that as the criterion speed of external TL increases, the strength of correlations with internal TL became weaker (Table 4). A possible explanation may be that GPS devices have been previously found to exhibit decreased reliability when measuring distance covered at high speeds.[2] These findings suggest that the volume of LSA is better related to external TL than the volume of HSR or VHSR, when compared with internal TL. Nonetheless, the volume of HSR and VHSR may still provide important information pertaining to the external TL of soccer players.

Due to the increased contribution of anaerobic metabolism to high-intensity activities, HR measures may respond slowly to short bouts of HSR and VHSR.[9] Thus, the physiological response to short bouts of HSR and VHSR and, in turn, HR-based internal-TL measures may be underestimated. Furthermore, research has established that team-sport athletes spend a large volume of time standing and moving at low speed while listening to coaching instructions and waiting to perform drills during field-based training.[24] Therefore, periods of HSR and VHSR are interspersed with extensive recovery, which may result in decreased perception of effort. As a result of this, the sRPE method may underestimate the stress imposed by HSR and VHSR. Indeed, previous research has noted small to moderate correlations between the sRPE- and HR-based methods during resistance training and soccer match play, possibly due to the intermittent, high-intensity nature of these activities.[1] These factors could account for the smaller correlations between HSR and VHSR volume, and internal TL (Table 4). The external-TL measures of HSR and VHSR may provide further detail on high-intensity activities, which is not reflected by internal TL. However, the TL imposed specifically during high-intensity training drills and periods of HSR and VHSR was not separately quantified in the current investigation. Further research is needed to compare physiological, perceptual, and physical measures of intensity and TL exclusively during high-intensity activities.

It should be highlighted that the use of speed to assess the physiological demands of intermittent activity may be limited, as this paradigm is based on the assumption that increased movement speed denotes greater exertion.[25] High-intensity bouts including jumps, turns, physical contacts, and unorthodox movements (eg, backward and lateral movements, shuffling, diving) may therefore be classified under a low-speed locomotor category, despite imposing a high physiological load on the player.[26] The metabolic cost associated with soccer-specific activities such as dribbling, heading, and kicking may also be underestimated, as these have been found to incur greater physiological demands than running alone at the same speed.[27] It is therefore vital to ensure that physical measures derived from speed and displacement data are considered within the context of external running demands.

The use of accelerometer technology to quantify the external TL of professional soccer players was recently assessed by Gomez-Piriz et al.[15] While that study concluded that the accelerometer-derived total body load is not a valid measure of external TL in soccer, the devices and equations used to calculate external TL were different than those used in the current investigation. In contrast to these findings, the accelerometer-derived player-load equation has previously provided large correlations with the sRPE method in Australian football.[4] However, the current study is the first to compare player load against other measures of TL in professional soccer players. This vector magnitude accumulates during skill-based movements, tackles, and other nonrunning activities[28] and may therefore provide a better indication of the demands imposed by soccer-specific nonrunning activities than the GPS-based speed data alone. Accelerometers in the GPS devices used in the current study have previously demonstrated acceptable interdevice reliability and validity when quantifying the movement and collision demands of Australian football and rugby league.[13,16] In the current study, player load was found to correlate largely with Banister's TRIMP and Edwards' TRIMP methods of internal TL assessment. A large correlation was also found between the sRPE method and player load. Collectively, these results suggest that the player load is an acceptable measure of external TL and is largely related to players' physiological and perceptual responses to training stimulus in professional soccer.

The large relationship between TD and accumulated player load found in the current study (r = .93) suggests that the magnitude of player load may highly depend on accelerations measured from vertical motion (z-axis), which occurs as a consequence of locomotion at any speed.[29] It has been proposed that an athlete whose main activity is running may provide large relationships between player load and TD, due to the vertical accelerations generated by each heel strike.[28] Therefore, while the player load provided large correlations with measures of internal TL, additional research is required to examine its ability to quantify the external TL imposed by soccer-specific activities.

It is important to note that the current study was limited by the amount of data collected for individual players. As a consequence, the correlation coefficients in this study reflect the relationship between measures of TL from the pooled data rather than the mean of intrasubject correlations, as is commonly performed in the literature. Nonetheless, as many correlations found in the current study are in agreement with previous research, and some new variables have been correlated, these results still provide important information for sport scientists and practitioners.

In conclusion, large correlations were found between measures of internal TL, in agreement with previous research.[1,7,8] Physical measures of TD, LSA volume, and player load were found to have the strongest relationships with measures of internal TL and may therefore provide acceptable monitoring tools for coaches and sport scientists. Physical-performance measures including HSR volume and VHSR volume were found to provide large and moderate correlations, respectively, with internal TL measures. While further research is needed, it is suggested that these measures may reflect high-intensity information not assessed by perceptual and physiological measures.

Practical Implications

The prescription of individualized exercise programs in a periodized training schedule relies on measures of TL[7] and feedback regarding the response of a player to such loads. Precise quantification of the various forms of TL experienced by an individual may contribute to a more comprehensive understanding of how the athlete is responding to the prescribed training and assist in subsequent alterations to the training program.[7] Furthermore, long-term monitoring of TL may help soccer coaches control the training process, which can enhance performance.[1] This may also allow coaching staff to identify the individualized relationships between measures of internal TL and external TL for specific players and possibly provide warning signs of overtraining or overreaching (ie, deviations in the relationship between sRPE TL and player load). While it is important to acknowledge that internal TL and external TL are vastly different constructs, results from the current study suggest that TD, LSA volume, and player load are acceptable indicators of external TL during field-based training for professional soccer compared with measures of internal TL. Physical activity measures including HSR and VHSR volume are somewhat related to internal TL and may provide additional information not reflected in perceptual and physiological methods.

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