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**TITLE:** INTERNAL AND EXTERNAL MATCH LOADS OF UNIVERSITY-LEVEL SOCCER PLAYERS: A COMPARISON BETWEEN METHODS

**RUNNING HEAD:** INTERNAL AND EXTERNAL MATCH LOADS OF SOCCER PLAYERS

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**ABSTRACT**

The aim of this study was to use individualized intensity zones to compare the external (velocity and Player Load, PL) and internal loads (heart rate, HR) of a cohort of university-level soccer players. Thirteen soccer players completed a 40 m maximum speed test and the Yo-Yo Intermittent Recovery Test 1 (Yo-Yo IR1) to determine individualized velocity and HR thresholds. HR values and global positioning system (GPS) data of each player were recorded during five league matches. A large ($r = 0.46$; $p \leq 0.01$) correlation was found between time spent in the low-intensity (LI) velocity zone (LIVZ) and the LI HR zone. Similarly, there were moderate ($r = 0.25$; $p \leq 0.01$) to large ($r = 0.57$; $p \leq 0.01$) correlations between the relative and absolute time spent in the moderate-intensity (MI) velocity zone (MIVZ) and the MI HR zone. No significant correlations ($p \leq 0.01$) existed between the high-intensity (HI) velocity zones (HIVZ) and the HI HR zone. On the other hand, PL showed significant correlations with all velocity and HR (absolute and relative) variables, with the exception of an non-significant correlation between the HI HR variables and PL. To conclude, PL showed good correlations with both velocity and HR zones and therefore may have the potential to serve as a good indicator of both external and internal soccer match loads.

**KEY WORDS**: GPS, heart rate, match analysis, soccer, player load

## INTRODUCTION

A thorough understanding of the loads placed on soccer players during match-play allows for specific training and recovery programs to be developed, which in turn may lead to a decrease in injuries and improvement in performance. The load players experience during match-play can be categorized into either "external" (i.e. the 'work' performed), or "internal" loads (i.e. the physiological response to the 'work' performed) (17). Generally, time-motion analyses, employing video and global positioning systems (GPS) are used to determine external loads during match-play, and heart rate (HR) telemetry to determine internal loads (12, 13, 28, 30). In order to obtain an accurate match load profile, researchers and sport scientists should use methods that allow for the simultaneous analyses of both internal and external match loads of players (1).

Although various methods enable researchers to measure the external match loads of players, literature suggest that GPS analysis is more accurate than manual video tracking and less expensive than semi-automated video tracking (3, 10). Additionally, GPS analysis can be used to integrate both motion analysis and HR analysis. Although GPS technology provides quantitative data on the position, displacement, velocity, decelerations and accelerations of players on the field (11), small skill-based movements (with limited horizontal displacement) such as passing and kicking within congested spaces are not accurately measured by using this technology. Therefore, external match loads may be underestimated if all forms of fatiguing movements are not considered.

Montgomery et al. (22) proposed that accelerometers can be used to determine all forms of external loads in team sports. Triaxial accelerometers are highly sensitive motion sensors that measure the frequency and magnitude of movements in three dimensions (anterior-posterior, mediolateral and longitudinal) (4). Furthermore, accelerometers have the potential to indicate gross fatiguing movements, not just locomotive activities (4). Also, a study performed on boys basketball players revealed significant correlations (r = 0.54–0.81) between accelerometer data and HR (8). However it should be noted that this study used a uniaxial accelerometer which could have underestimated the external loads as it only measured movement in one plane. In addition to the correlation between HR and accelerometer data, Boyd et al. (4) found a large relationship (r = 0.63–0.76) between Player Load (PL), an accelerometer derived measure, and locomotor distance covered.

Recent rule changes by Federation Internationale de Football Association (FIFA) allow GPS monitoring during competitive matches, but unfortunately HR analysis is still not permitted. Although accelerometer data (or PL) has the potential to serve as an accurate measure of external loads, limited research has investigated the relationship between PL and HR across a range of intensities. Therefore the aim of this study was to use individualized intensity zones to compare the external (velocity and PL) and internal (HR) loads of a cohort of university-level soccer players. These results may provide sports practitioners with a better understanding of the amount of external and internal loads players experience during soccer match-play. Results may also help identify the external loads that more associated with physiological responses to match-play.

## METHODS

### Experimental approach to the problem

The null hypothesis for this study was that no significant relationships would exist between the external and internal match loads of university-level soccer players. A selected group, cohort research design was used to test the study hypothesis. HR values and GPS data of each player were recorded during five league soccer matches.

### Subjects

Subjects consisted of a group of 13 male soccer players from a university in the North West Province of South Africa. Players' age, body stature and mass (mean±SD) were: 22.6 ± 2.5 years, 175.3 ± 7.1 cm and 62.9 ± 10.0 kg respectively. Goalkeepers were not included in the study. Players trained five times a week for 1.5 hours per training session and participated in one league match per week. As the research took place during the peak period of the periodization cycle, training mainly focussed on technical and tactical aspects. The team competed in the provincial A-league. Objectives of the study were explained to players, after which they all completed an informed consent form. Ethical approval was granted by the Health Research Ethics Committee of the institution where the research was conducted (NWU-00200-14-A1). The study was conducted according to the ethical guidelines and principles of the international Declaration of Helsinki and the National Health Research Ethics Council of South Africa. The maximum speed, maximum oxygen uptake ($\dot{V}O_{2max}$) test and five matches took place during a 4-week period with tests taking place on the same day in the middle of this period. Testing took place during the normal training time of the team which coincided with the usual match-play time. The average temperature during testing and the matches was 17.6 ± 3.2 ˚C. For players' match data to be included in the study, they were required to finish the entire match. Furthermore, subjects had to complete the maximum speed and $\dot{V}O_{2max}$ test whilst being injury free. The injury status of a player was self-reported via a demographic questionnaire. Players had to achieve their $\dot{V}O_{2max}$ to be included in the study. All players not adhering to these criteria were excluded from the study.

**Testing Procedures**

Players completed a test battery which consisted of a 40-m maximum speed test, followed by the execution of a Yo-Yo IR1 test. These tests were performed to determine the individual velocity and HR thresholds of each player for use during match analyses. GPS units together with Fix Polar Heart Rate Transmitter Belts (Polar Electro, Kempele, Finland) were used to monitor velocity and heart rates during five university-level soccer matches.

*40-m maximum speed test.* The 40-m maximum speed test was preceded by a standardized warm-up consisting of jogging and dynamic stretches followed by 10-minute bursts of running.

The time for the 40-m maximum speed test was measured using photocells (Brower Timing Systems, South Draper, UT) placed at the start, 30 and 40 m on a grass soccer field. Players wore their soccer boots during execution of the speed test. When ready, players sprinted from a static position. Each subject performed 2 trials separated by at least 3 minutes of rest, and the fastest time was recorded to the nearest 0.01 s. To determine the maximum velocity ($m.s^{-1}$) of each player, the 30-m split time was subtracted from the 40-m split time. Ten (representing 10 m) was then divided by this value (26).

Velocity thresholds suggested for soccer by Dwyer and Gabbett (11) were used for this study. Thresholds were determined as a percentage of each player's maximum velocity (as obtained from the 40-m maximum speed test). The general threshold speed guidelines of Dwyer and Gabbett (11) show that the moderate-intensity velocity zone (MIVZ) is between 34% and 61% of players' maximum velocity; the low-intensity velocity zone (LIVZ) was therefore set at <34% of maximum velocity and the high-intensity velocity zone (HIVZ) at >61% of the maximum velocity. For a movement to be recorded as an effort players had to maintain that velocity for at least 0.5 s.

*Yo-Yo IR1*. The Yo-Yo intermittent recovery test, level 1 (Yo-Yo IR1) was chosen as the preferred test for this study in view of the fact that it has shown a significant correlation ($r = 0.71$; $p < 0.05$) with the amount of high-intensity running performed during a soccer match (20). A significant correlation between $\dot{V}O_{2max}$ and Yo-Yo IR1 results ($r = 0.70$, $p < 0.05$) also provides evidence that the Yo-Yo IR1 is a valid exercise test for determining players' $\dot{V}O_{2max}$ values (2). All players were familiar with the Yo-Yo IR1 as they had performed it previously before commencement of the study. The test was conducted outside on a flat, clearly marked 20 m stretch of a grass soccer field. Players wore their soccer boots during the test. Players were required to run back and forth on the 20-m track and pace themselves so that the arrival at the end of the 20-m stretch coincided with the signal emitted from a commercially available prerecorded compact disc (CD) (Bangsbosport.com, Bangsbosport Aps, Espergaerde, Denmark). Players were required to cross the marked lines at either end of the 20-m stretch with one foot as the signal sounded from the CD. Players received a brief 10-s active recovery after each 40-m (2 x 20 m) shuttle during which they walked back and forth over a 5-m stretch. The test started at a speed of 10 $km.h^{-1}$ and was progressively increased until test termination. The test was terminated due to players voluntarily stopping or when a player could not make it to either end marks of the 20-m distance within the given signal time in two successive shuttles.

Players performed the Yo-Yo IR1 while wearing a Fix Polar Heart Rate Transmitter Belt (Polar Electro, Kempele, Finland), and a portable gas analyser apparatus (Metamax 3B, Cortex, Leipzig, Germany) which were used to sample expired air and record HR continuously. The rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), respiratory exchange ratio (RER) and HR were recorded every 5 s. The MetaMax 3B is regarded to be a reliable and valid portable gas analyser (26). The portable gas analyser was calibrated with standard gases before commencement of the test. The criteria for reaching $\dot{V}O_{2max}$ was set as follows: a respiratory exchange ratio-value higher than 1.15 at test termination; oxygen consumption ceased to rise and reached a plateau or began to fall even though the work rate continued to increase, or the maximal age-specific HR was reached (9, 21).

The ventilatory threshold (VT) was determined by applying the criteria of an increase in $\dot{V}_E/\dot{V}O_2$ with no increase in $\dot{V}_E/\dot{V}CO_2$ and departure from the linearity of $\dot{V}_E$ (7). The respiratory compensation point (RCP) was taken as the point which corresponded to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (7). VT and RCP were visually detected by two independent experienced researchers. This method is reliable (r = 0.91–0.97, $p$ <0.0001) for the determination of both VT and RCP (28). The different gas exchange phases were used to determine the heart rates that corresponded to three exercise intensities (7): Heart rates that correspond to the exercise intensities below VT were classified as low-intensity heart rates; heart rates between VT and RCP as moderate-intensity heart rates; and heart rates above RCP as high-intensity heart rates.

*Match analyses.* GPS data of the starting line-up were monitored for the duration of five matches. All matches were analyzed with GPS units sampling at a frequency of 10 Hz (MinimaxX V4.0, Catapult Innovations, Victoria, Australia). The average number of satellite signals was 10.1 ± 0.1 and horizontal dilution of precision was 0.96 ± 0.05. Units were kept under open sky and turned on 10 min before each match. GPS units were fitted to the upper back of each player by means of a harness. Players were familiar with the GPS equipment having trained with the units prior to the study. GPS units collected information on distances, velocities and intensities of all movements executed during different soccer matches. For a movement to be recorded as an effort, players had to maintain that velocity for at least 0.5 s. Furthermore an Intelligent Motion Filter was added to filter data and remove erroneous GPS information. The GPS Doppler data was used during analyses of GPS-related variables.

Accumulated player load (PL) was calculated from the triaxial accelerometers sampling at 100 Hz. PL is an estimate of physical demand combining the instantaneous rate of change in acceleration in the following three planes: anterior-posterior X, mediolateral Y, and longitudinal Z (23). The validity and reliability of the GPS units and the PL calculation have been described elsewhere (5, 19, 29). Recordings from GPS units were downloaded to a PC and analyzed using the Logan Plus V4.7.1 software (Catapult Sports, Victoria, Australia).

**Statistical Analyses**

Analyses were conducted using IBM SPSS Statistics v. 21.0.0.0. Firstly, the velocities and heart rates obtained from each player during matches were categorized into the three intensity zones (low, moderate and high) according to the Yo-Yo IR1 test results and speed test. Times spent in different zones were then expressed as a percentage of the total match time (excluding the time before the matches and half-time). Secondly, descriptive statistics (averages, minimum, maximum and standard deviation values) for each variable were calculated. Thirdly, Spearman's rank correlation rho was used to determine the relationship between the time spent (relative and absolute) in a velocity zone, the corresponding HR zone and the PL. In addition to the Spearman's rank correlation, a partial correlation was performed to adjust for players' $\dot{V}O_{2max}$ values and Yo-Yo IR1 performance. A Fisher r to z transformation was calculated to determine the 90% confidence interval (CI) from the correlation coefficient (*r*). The level of significance was set at $p \leq 0.01$. Strength of correlations was categorized according to the following criteria: <0.1 (trivial), <0.3 (small), <0.5 (moderate), <0.7 (large), <0.9 (very large) and <1 (nearly perfect) (16).

## RESULTS

Descriptive statistics of the Yo-Yo IR1 as well as match variables are presented in Table 1. Players achieved a mean $HR_{max}$ of 194 ± 7 bpm and covered an average distance of 1618 ± 429 m during the Yo-Yo IR1. Furthermore, players achieved a mean match HR of 158 ± 10 bpm and covered an average distance of 9329 ± 1286 m.

****Place Table 1 about here****

Table 2 presents the absolute and relative time spent in the different intensity zones during matches. Results show a large (r = 0.46; $p \leq 0.01$) correlation between the time spent in the LIVZ (5017 ± 368 s) and the LI HR zone (2891 ± 1086 s), with the true correlation value varying between moderate and large. Similarly, moderate (r = 0.25; $p \leq 0.01$) to large (r = 0.57; $p \leq 0.01$) correlations were found between the relative (11.4 ± 3.7%) and absolute time (669 ± 223 s) spent in the MIVZ and the MI HR zone (41.0 ± 16.8% and 2253 ± 752 s). However, the true correlation value for the absolute time spent in the MI zone fell between the large to very large category, whereas the correlation for the relative time was small to moderate. There were no significant correlations ($p$ ≤0.01) between the HIVZ and the HI HR zone. Only small correlations were found between variables when adjusting for $\dot{V}O_{2max}$ and Yo-Yo IR1 performance. On the other hand, PL showed significant correlations with all velocity and HR (absolute and relative) variables. The only exception was a non-significant correlation between the HI HR variables and PL.

****Place table 2 about here****

## DISCUSSION

The present study compared match analysis results of different external and internal match loads in a cohort of university-level soccer players. This study is the first to use individualized thresholds to concurrently determine the internal and external loads of several competitive university-level soccer matches. The main finding of this study was that PL showed significant correlations with all velocity variables and HR except for the HI zones. Also, there were moderate to large correlations between the velocity and HR zones. Furthermore, when adjusting for Yo-Yo IR1 performance and $\dot{V}O_{2max}$, only small correlations were found between external and internal match load-related variables. In view that these correlations became less significant when adjusting for the fitness of players, we can assume that the relationship between HR, velocity and PL is related, at least in part, to the fitness levels of players.

Without the adjustment for fitness levels the results showed that high correlations between velocity and HR were present while players were spending time in low- to moderate-intensity zones, but decreased as players moved into the higher intensity zones. During soccer matches HR does not immediately respond to sudden velocity increases, which may explain the differences in correlation values between different intensity zones (25). In support of this notion previous studies indicated that the validity of heart rate information at high speeds may be questionable (14, 27). It is also possible that actions with no horizontal displacement (such as tackling and jumping) will not be included in the HIVZ but may still elicit a significant heart rate response. Previously, researchers also found that the validity and reliability of GPS devices for measuring distance decreased as movement velocities increased (18), which may also serve as an explanation for lower correlations between velocity and HR in higher intensity zones.

The monitoring of only external GPS loads during match-play may underestimate actual loads that players experience during matches due to extra skills (e.g. dribbling, kicking etc.) that are unaccounted for (24). To counter this we investigated correlations between PL, HR and velocity zones. PL showed larger correlations with HR than correlations found between movement velocity and HR. Others also observed a moderate correlation ($r = 0.33$; $p < 0.001$) between PL and the mean HR during small-sided soccer matches (6). In addition Montgomery et al. (22) reported significant relationships between PL, HR and blood lactate during basketball matches and training. These results indicate that PL is a better indicator of external and internal loads experienced by players during match-play than velocity and distance measures. As GPS monitoring is now allowed during official matches but heart rate monitoring is not, PL may serve as a surrogate indicator for the physiological stress of players. However, it is noteworthy that neither velocity based measures nor PL correlated well with HR at higher intensities in our study, which stresses the importance of using velocity measures, PL, and HR simultaneously to obtain an accurate indication of match loads. These results also indicate the need to investigate other possible internal load measures (e.g. session-RPE) to determine match loads.

Lastly, the average $HR_{max}$ achieved during matches was higher than the average $HR_{max}$ achieved during the Yo-Yo IR1. A great number of decelerations and accelerations, which are energetically very demanding activities, take place during soccer matches (27). In contrast players only performed a few accelerations and decelerations during the execution of the Yo-Yo IR1. Movement requirements of soccer matches will therefore tax the cardiovascular system to a greater extent than the Yo-Yo IR1, which would give rise to higher $HR_{max}$ values. Furthermore, psychophysiological challenges associated with match participation will lead to more intensified physiological responses compared to training responses (15). Differences in heart rate responses between competitive matches and tests that are aimed at producing maximal physiological responses, suggest that in the present cohort, competitive environments may be necessary in order to appropriately assess these responses.

In summary, this is the first study to use individualized thresholds to concurrently determine the internal and external loads of competitive university-level soccer matches. Results revealed moderate to large correlations between the velocity and HR match loads at low and moderate intensities, but only small correlations at high-intensities. However, PL showed better correlations with both velocity and HR zones suggesting that it is a good indicator of both external and internal loads. It is important to note that these correlations are dependent on players' fitness levels. Also, both velocity measures and PL showed poor correlations with HR at high intensities. However, results of the present study must be interpreted with caution, since a small sample size was used. Results are also only applicable to university-level soccer players.

**PRACTICAL APPLICATIONS**

When analyzing soccer matches it is important to consider the use of individual determined thresholds to examine both internal and external loads of players. The use of GPS alone leads to an underestimation of match loads due to skill-based movements (e.g. dribbling, kicking, etc.) which are not detected. On the other hand, PL could be a good indicator of both the external and internal loads at low to moderate intensities during match-play. However, due to higher physiological responses during match-play compared to simulated environments, practitioners should make use of real matches to analyze and evaluate loads.

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**TABLE 1:** Minimum, maximum and average values for the Yo-Yo IR1 as well as the internal and external match load-related variables.

| Variables | Average ± SD | Min | Max |
|---|---|---|---|
| Yo-Yo IR 1 $HR_{max}$ (bpm) | 194 ± 7 | 183 | 202 |
| Yo-Yo IR 1 distance (m) | 1618 ± 429 | 1080 | 2240 |
| $\dot{V}O_{2max}$ (ml.kg.$^{-1}$min$^{-1}$) | 61.9 ± 3.7 | 53.0 | 68.0 |
| VT HR (bpm) | 164 ± 10 | 144 | 177 |
| VT HR (%) | 84.5 ± 4.5 | 73.1 | 88.9 |
| RCP HR (bpm) | 187 ± 6 | 179 | 196 |
| RCP HR (%) | 96.6 ± 1.4 | 94.3 | 98.4 |
| Maximum testing velocity (m.s$^{-1}$) | 8.6 ± 0.3 | 8.0 | 9.0 |
| MIVZ start (m.s$^{-1}$) | 2.9 ± 0.1 | 2.7 | 3.1 |
| HIVZ start (m.s$^{-1}$) | 5.2 ± 0.2 | 4.9 | 5.5 |
| Match distance covered (m) | 9329 ± 1286 | 6249 | 11511 |
| Relative match distance covered (m.min$^{-1}$) | 96.3 ± 11.7 | 63.3 | 117.5 |
| Maximum match velocity (m.s$^{-1}$) | 7.8 ± 1.4 | 6.2 | 15.0 |
| Average match velocity (m.s$^{-1}$) | 1.6 ± 0.2 | 1.1 | 2.0 |
| Match $HR_{average}$ (bpm) | 158 ± 10 | 139 | 176 |
| Match $HR_{max}$ (bpm) | 200 ± 11 | 180 | 220 |
| PL (au) | 997 ± 230 | 562 | 1438 |

Yo-Yo IR1 – Yo-Yo intermittent recovery test 1; $HR_{max}$ – Maximum heart rate; $\dot{V}O_{2max}$ - Maximum oxygen uptake; VT – Ventilatory threshold; HR – heart rate; RCP – Respiratory compensation point; MIVZ – Moderate-intensity velocity zone; HIVZ – High-intensity velocity zone; $HR_{average}$ – Average heart rate; PL – Accumulated Player Load; au – arbitrary unit

**TABLE 2:** The absolute and relative time spent in different intensity zones during matches (n = 44).

| Variable | Velocity | HR | *PL* | *Vel vs HR* *r* *(90% CI)* | *Vel vs PL* *r* *(90% CI)* | HR vs PL *r* (90% CI) |
|---|---|---|---|---|---|---|
| **LI zone (s)** | 5017 ± 368 | 2891 ± 1086 | 4181 ± 474 | 0.46*[L] | 0.92*[VL] | 0.54*[L] |
| | | | | 0.32 to 0.58 | 0.90 to 0.94 | 0.41 to 0.65 |
| **LI zone (%)** | 87.2 ± 4.1 | 49.4 ± 20.9 | 72.0 ± 8.1 | 0.14 | 0.84*[L] | 0.24* |
| | | | | -0.02 to 0.28 | 0.78 to 0.88 | 0.09 to 0.39 |
| **MI zone (s)** | 669 ± 223 | 2253 ± 752 | 1238 ± 324 | 0.57*[L] | 0.90*[VL] | 0.61*[L] |
| | | | | 0.45 to 0.67 | 0.86 to 0.92 | 0.49 to 0.70 |
| **MI zone (%)** | 11.4 ± 3.7 | 41.0 ± 16.8 | 21.2 ± 5.4 | 0.25*[M] | 0.83*[L] | 0.37*[M] |
| | | | | 0.10 to 0.39 | 0.78 to 0.87 | 0.23 to 0.50 |
| **HI zone (s)** | 80 ± 33 | 370 ± 503 | 387 ± 214 | 0.10 | 0.81*[L] | 0.10 |
| | | | | -0.06 to 0.26 | 0.74 to 0.85 | -0.06 to 0.26 |
| **HI zone (%)** | 1.3 ± 0.6 | 5.1 ± 7.6 | 6.8 ± 3.6 | 0.03 | 0.64*[L] | 0.02 |
| | | | | -0.13 to 0.18 | 0.54 to 0.72 | -0.13 to 0.18 |

LI – Low-intensity; MI – Moderate-intensity; HI – High-intensity; HR – Heart rate; PL – Player load; **p* ≤0.01; [M/L/VL] – Moderate/ large/ very large correlation