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Within-Match PlayerLoad Patterns During a Simulated Soccer Match: Potential Implications for Unit Positioning and Fatigue Management

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***Purpose**:* To assess the acute alterations in triaxial accelerometry (PlayerLoad [PL_{VM}]) and its individual axial planes (anteroposterior PlayerLoad [PL_{AP}], mediolateral PlayerLoad [PL_{ML}], and vertical PlayerLoad [PL_{V}]) during a standardized 90-min soccer match-play simulation ($SAFT^{90}$). Secondary aims of the study were to assess the test–retest reliability and anatomical location of the devices. ***Methods**:* Semiprofessional (n = 5) and university (n = 15) soccer players completed 3 trials (1 familiarization, 2 experimental) of $SAFT^{90}$. PlayerLoad and its individual planes were measured continuously using micromechanical-electrical systems (MEMS) positioned at the scapulae (SCAP) and near the center of mass (COM). ***Results**:* There were no between-halves differences in PL_{VM}; however, within-half increases were recorded at the COM, but only during the 1st half at the SCAP. Greater contributions to PL_{VM} were provided by PL_{V} and PL_{ML} when derived from the SCAP and COM, respectively. PL_{VM} (COM 1451 ± 168, SCAP 1029 ± 113), PL_{AP} (COM 503 ± 99, SCAP 345 ± 61), PL_{ML} (COM 712 ± 124, SCAP 348 ± 61), and PL_{V} (COM 797 ± 184, SCAP 688 ± 124) were significantly greater at the COM than at the SCAP. Moderate and high test–retest reliability was observed for PlayerLoad and its individual planes at both locations (ICC .80–.99). ***Conclusions**:* PlayerLoad and its individual planes are reliable measures during $SAFT^{90}$ and detected within-match changes in movement strategy when the unit was placed at the COM, which may have implications for fatigue management. Inferring alterations in lower-limb movement strategies from MEMS units positioned at the SCAP should be undertaken with caution.

***Keywords**:* accelerometry, MEMS unit, fatigue

Monitoring players' volume and intensity of training and competition is now commonplace in professional team sports. While the internal load represents the stimulus for adaptation,[1] competition regulations rarely permit its measurement,[2] and therefore research and technological developments have focused on the players' external load, referring to their locomotive or mechanical "output," to monitor training and competition loads. Conceptually, optimizing player readiness for competition and reducing noncontact-injury incidence, by informing training prescription and recovery protocols, represent the return on the technology and expertise investment required to monitor external load on a routine basis.

Traditionally, running distance at high speeds has been used as a key external-load metric; however, this is limited because it disregards energetically demanding changes in running speed[3,4] and is highly variable between team-sport matches.[5,6] More recently, an energetic model to quantify the metabolic cost of acceleration and deceleration has been adopted to facilitate the interpretation of external loads incurred for team-sport matches[4,7] and training sessions.[8] While a valuable addition to practitioners' monitoring system, the metabolic-power approach is constrained with compromised measurement accuracy in tracking high accelerations and decelerations with global positioning systems (GPS)[9] and the model's inability to quantify other taxing activities such as impacts, jumps, and changes of direction, which are inherent features of team sports. Accordingly, high-resolution triaxial accelerometers have been incorporated within MEMS (micromechanical electrical systems) devices containing GPS, with a vector-magnitude algorithm termed PlayerLoad (PL_{VM}) being the most commonly used metric in the research literature.[10–12]

Although PL_{VM} has been used as an external-load metric,[10,11] between-players comparisons are untenable due to the high degree of variability[12] considered to reflect the individuals' running mechanics or economy. However, another potential application of triaxial-accelerometer data is to detect changes in an individual's movement mechanics owing to fatigue. Using this technology, Mooney et al[13] found that players categorized in a state of chronic neuromuscular fatigue demonstrated a reduced vertical loading during Australian Football League matches and speculated that vertical stiffness or less-frequent abrupt changes in running velocity explained the altered mechanical strategy. While an attractive hypothesis, the high degree of match-to-match variation in team-sport running demands[5,6,14] and the strong association between total distance covered and PL_{VM}[11,15] combine to cast some uncertainty on the detection of altered movement efficiency in stochastic team-sport activities.

Therefore, to overcome the variability in soccer match play, we designed the current study to examine the PL_{VM} response to a 90-minute laboratory controlled soccer match-play simulation ($SAFT^{90}$)[16] in which the running demands of each 15-minute segment are standardized. This experimental model enables us to determine any uncoupling in the mechanical loading response to a standardized

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locomotor load in an intermittent and multidirectional fashion indicative of team-sport activity. Data of this nature permit an evaluation of the time course of movement economy during a simulated soccer match, which examines the utility of PL_{VM} and may also have implications for injury epidemiology, since increased injury risk is associated with fatigue at the latter stages of each half of match play[16–18] and training sessions.[18,19]

A secondary aim of this study was to examine the influence of accelerometer positioning on the PL_{VM} responses during simulated soccer match play. While the accelerometers harnessed in GPS units are positioned on the upper trunk to enhance the signal communication with satellites, the center of mass (COM) is considered the criterion location for measurement of overall body movement using accelerometers.[20] Since upper-body movements affect planar-loading distribution with unit positioning at the trunk,[12] we aimed to determine if the unit positioning influenced the time course of PL_{VM} responses to simulated match play. Finally, the within-device test–retest reliability (5.9% CV) of PL_{VM} has been demonstrated during treadmill running.[12] However, to facilitate meaningful interpretation of PL_{VM} during team-sport activity, an assessment of test–retest reliability during intermittent and multidirectional running is required; hence, our third aim was quantify this using a repeated-measures design.

Method

Twenty semiprofessional (n = 5) and university-level (n = 15) soccer players volunteered to participate in the study (mean ± SD age 22 ± 3 y, height 1.80 ± 0.06 m, body mass 78.9 ± 8.6 kg). The study was granted ethical approval from the departmental ethics committee before the commencement of the study. Participants were informed of the risks and discomforts associated with maximal testing and provided written informed consent.

Participants were required to visit the laboratory on 3 separate occasions. The $SAFT^{90}$ protocol was performed during all 3 visits. Tests were administered at the same time on each day (7 d apart) to attenuate circadian variation. The first laboratory visit was deemed a familiarization trial, during which participants became habituated to the movement actions involved during $SAFT^{90}$ and no data were recorded. Before the second laboratory visit, participants recorded their 6-day exercise program together with dietary intake for the 24-hour period before arrival and were instructed to replicate these routines in preparation for the third laboratory visit. Players performed a standardized 20-minute soccer-specific warm-up, followed by a 5-minute passive recovery period, before undertaking the $SAFT^{90}$ protocol, which consisted of two 45-minute halves (a fixed 15-min activity profile repeated 3 times in each half) interspersed with a 15-minute passive rest to replicate the halftime period.[16] The $SAFT^{90}$ incorporates multidirectional movements and replicates the time–motion analysis data typical of English championship soccer match play. Players navigate around a 20-m agility course, covering a total distance of 11.1 km and high-speed-running distance (>15km/h) of 2.04 km. The activity profile consisted of 1332 changes of direction and 1269 changes in speed over a 90-minute period.[17] During the simulation, participants' PlayerLoad data were collected (MinimaxX S4, Catapult Sports, Melbourne, Australia) for each 15-minute activity profile. We elected to use $SAFT^{90}$ to mimic the demands of soccer matches principally because the external-load "dose" in each 15-minute segment, and between laboratory visits, is standardized, thus enabling us to detect changes in movement strategy with prolonged soccer-specific exercise.

The MinimaxX (Catapult Innovations, Scoresby, Victoria) contained a triaxial piezoelectric linear accelerometer (Kionix: KXP94) that sampled at a frequency of 100 Hz. Before every test, the accelerometers were calibrated according to the manufacturer's instructions. One accelerometer was then positioned between the scapulae (SCAP) and another close to the COM, in a neoprene undergarment that accommodates the units in integrated pouches. Both units were affixed with experimental tape to limit movement artifact during the simulation. The COM pouch was positioned at the intersection of the axial and sagittal planes in line with the iliac crest on the posterior aspect of the frontal plane. Accelerometer research in human locomotion suggests that the COM is the optimal location to determine overall body accelerations.[12,20] Consequently, for the purpose of this study, we assumed COM as the criterion placement for PlayerLoad. Combined triaxial-accelerometer data were presented as PlayerLoad, which is a modified vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the 3 planes divided by 100.[12,21] In addition to the vector-magnitude PlayerLoad (PL_{VM}), its individual-component planes (anteroposterior PlayerLoad [PL_{AP}], mediolateral PlayerLoad [PL_{ML}], and vertical PlayerLoad [PL_V]) were also recorded to determine the source of any differences owing to accelerometer positioning. Expressed in arbitrary units (au), PlayerLoad data were recorded throughout the $SAFT^{90}$ using Catapult Sprint software (Version 5.0.9.2; Firmware 6.75).

Data were transferred from the Catapult Sprint software by exporting the Excel configurable reports into IBM SPSS Statistics for Windows software (release 20; SPSS Inc, Chicago, IL, USA). A 2-way repeated-measures ANOVA was used to assess differences in PL_{VM}, PL_{AP}, PL_{ML}, and PL_V between halves and 15-minute epochs and between unit locations (SCAP and COM). Where the sphericity assumption was violated a Huynh-Feldt correction was applied to the degrees of freedom. Post hoc pairwise comparisons, with Sidak-adjusted P values, were conducted in the event of a statistically significant F-ratio. Two-tailed statistical significance was accepted at $P \leq .05$, and measures of effect size (ES) were calculated using partial eta-squared (η^2). Magnitude of the ESs exceeding 0.02, 0.13, and 0.26 were considered small, medium, and large, respectively.[22]

Test–retest reliability of PlayerLoad variables measured at the 2 anatomical locations was examined via the intraclass correlation coefficient (ICC; 2-way random model for absolute agreement) and the within-subject coefficient of variation. We adopted the criteria of Vincent[23] to interpret the ICC coefficients, in which values greater than and including .90 were considered high, from .80 to .89 moderate, and below .80 questionable. Coefficient of variation was calculated by dividing the standard deviation of the between-trials differences by the square root of 2 and subsequently dividing this result by the grand mean derived from both trials. All data are presented as mean ± SD.

Results

There were no between-halves differences observed in PL_{VM} as determined from SCAP (514 ± 58 vs 512 ± 57; P = .795, ES = 0.19) and COM (727 ± 82 vs 724 ± 88; P = .143, ES = 0.19) measurements. PL_V was lower in the second half at both unit locations (SCAP 369 ± 41 vs 319 ± 106, P = .047, ES = 0.20; COM 420 ± 68 vs 377 ± 133, P = .045, ES = 0.15), but no between-halves differences were denoted in PL_{AP} (SCAP 185 ± 28 vs 160 ± 52, P = .659, ES = 0.17; COM 266 ± 35 vs 236 ± 76, P = .106, ES = 0.19) or PL_{ML} (SCAP 188 ± 24 vs 161 ± 53, P = .814, ES= 0.20; COM 382 ± 46 vs 331 ± 100, P = .259, ES = 0.24).

Irrespective of accelerometer variable or unit position, increased loading was observed in the 15- to 30-minute epoch versus the first 15 minutes of the $SAFT^{90}$ (P < .001–.042, ES = 0.26–0.69; Figure 1). For PL_{VM}, COM measures returned to baseline for the 45- to 60-minute period but increased in the final 15 minutes of the second half. SCAP-derived PL_{VM} was increased from baseline (0- to 15-min epoch) in the 15- to 30-, 30- to 45-, and 75- to 90-minute periods; however, there was no change over the course of the second half. PL_V at the COM returned to baseline values at the start of the second half (45–60 min) but was thereafter increased for the remainder of the $SAFT^{90}$. Figure 1 depicts other increases in accelerometer metrics versus 0- to 15-minute values, but no other within-half changes were observed. Within-match changes were also absent in the percentage contributions of each plane to PL_{VM} at both the SCAP (PL_V 45.2–51.0%, PL_{ML} 22.5–28.1%, PL_{AP} 23.4–29.1%) and COM (PL_V 35.8–41.2%, PL_{ML} 31.4–37.4%, PL_{AP} 23.0–27.2%) locations (P range .475–.844, ES range 0.27–0.49).

\<<<<<<<<<<<<**FIGURE 1**>>>>>>>>>>>>>\

There was a significant (P < .001) main effect for accelerometer data recorded at the COM and SCAP during the $SAFT^{90}$. COM placement resulted in higher values for PL_{VM} (1451 ± 168 vs 1029 ± 113, ES 0.90), PL_{AP} (503 ± 99 vs 345 ± 61, ES 0.86), PL_{ML} (712 ± 124 vs 348 ± 61, ES 0.97), and PL_V (797 ± 184 vs 688 ± 124, ES 0.39) than SCAP. The percentage contributions of PL_{AP} (SCAP 25.0% ± 1.6% vs COM 25.1% ± 2.1%, P = .945, ES 0.00) to the vector magnitude were not different between unit positions. However, the percentage contributions of PL_{ML} (SCAP 25.3% ± 2.8% vs COM 34.4% ± 3.0%, P < .001, ES 0.79) and PL_V (SCAP 48.7% ± 3.0% vs COM 39.5% ± 3.7%, P < .001, ES 0.81) were significantly different between unit positions.

With the exception of SCAP-derived PL_{AP} (moderate test–retest reliability), all accelerometer indices demonstrated high test–retest reliability when recorded at both the SCAP and the COM, according to the ICCs (Table 1). No systematic bias was observed for any accelerometer measure, and coefficients of variation ranged from 3.1% to 8.7%

\<<<<<<<<<<<<**TABLE 1**>>>>>>>>>>>>>\

Discussion

The study's primary aim was to examine the acute alterations of PlayerLoad during a simulated soccer match ($SAFT^{90}$). We also examined the influence of unit positioning on PlayerLoad responses to simulated soccer match play and test–retest reliability. The main findings for this study are as follows: (1) PL_{VM} did not change between playing halves for either unit location but demonstrated increases over time within each half when positioned at the COM, and (2) the percentage contribution of PL_V to the vector magnitude was greater when measured at the SCAP, whereas (3) PL_{ML} contributions to PL_{VM} were higher when determined at the COM, (4) accelerometer-derived metrics were higher when measured at the COM versus the SCAP, and (5) accelerometer metrics demonstrated moderate to high levels of reproducibility during soccer-specific exercise.

In this study we adopted a standardized soccer-specific exercise dose to examine the within-match changes in accelerometer metrics, which may provide information regarding a player's movement strategy, efficiency, or kinematic changes as a result of intermittent and multidirectional exercise. We observed no between-halves differences in PL_{VM}, which was not unexpected given the standardized exercise dose prescribed by the $SAFT^{90}$ protocol. An interesting observation was that within each half, there were increases in loading, which were particularly evident in the vector magnitude and the vertical plane when measured at the COM. Irrespective of the unit position and accelerometer metric, increased loading was observed in the 15- to 30- versus the 0- to 15-minute epoch in the first half. We are unable to determine the reason for this increase, but we note that its timing coincides with decrements in early rate of torque development and central motor output observed after 15 minutes of $SAFT^{90}$.[17] Suppressed torque-development rates may have implications for gait and postural control, but further research is required to examine this hypothesis. The increased accelerometer loading within each half may be indicative of an altered movement strategy or compromised movement efficiency owing to fatigue during soccer match play, perhaps due to either alterations in movement kinematics[24] or lower-limb stiffness.[25] The within-half increases in COM-derived PL_{VM} correspond with lower-limb fatigue observed after $SAFT^{90}$,[16,17] noncompetitive matches,[26,27] and other soccer-specific simulations.[28,29] This well-established fatiguing phenomenon in soccer activity has also been linked to epidemiological observations of increased injury incidence in the latter stages of each half of competitive soccer match play[18,19] and of training sessions.[19] Taken together, these findings suggest that the real-time monitoring of COM accelerometer data may identify players with an altered movement strategy owing to fatigue, which may have implications for training prescription, substitutions/interchanges, and injury prevention. However, further work is warranted to examine the utility of accelerometer data collected both acutely and chronically as a potential injury risk factor. Research is also needed to determine whether within-half changes in accelerometer data can be identified in competitive match-play scenarios where its stochastic nature results in marked variability of locomotor profiles in team-sport players.[5–7]

The within-match changes in accelerometer variables were not consistent when recorded at different anatomical positions. The increased loading when the MEMS device was positioned at the COM supports previous observations during treadmill running[12] and may reflect either increased mediolateral accelerations according to pelvic rotation or an increased sensitivity to vertical lower-limb accelerations. In this study, recordings of PL_{VM} at the COM showed increases in each half, while SCAP-derived measurements did not identify increases during the second half of simulated match play. We also observed higher mediolateral contributions at the COM and greater vertical-loading contribution to the SCAP-determined PL_{VM}. Changes in orientation of the MEMS device are not considered during accelerometer recordings, so we speculate that greater PL_{ML} contribution to PL_{VM} at the COM might be explained by pelvic rotation during the gait cycle. While the absolute accelerations in the COM-recorded vertical plane were larger, the greater PL_V contribution to the vector magnitude at the SCAP may result from movements in the device owing to shoulder-girdle movement during arm swing or to movement artifact within the undergarment. However, kinematic research is warranted to examine the source of these observations, and we acknowledge that these results may not translate into competitive match-play scenarios. Nonetheless, our data would seem to imply that upper-body kinematics influence the modulations of PL_{VM} when measured at the SCAP, and since MEMS devices are routinely placed in this location to enhance the GPS positioning signal, practitioners should be cautious in making inferences regarding lower-limb alterations in movement strategy. Given the low cost and unobtrusive nature of triaxial-accelerometer technology, placement at the COM (independent of MEMS devices) may be warranted during team-sport activity to provide real-time information regarding alterations in lower-limb movement strategy. Alternatively, MEMS device manufacturers may elect to modify existing vector-magnitude algorithms to negate the influence of upper-body movements.

While the application of accelerometer data is relatively embryonic in team sports, the data from this study suggest that PL_{VM} and data from its 3 component planes are robust metrics during team-sport-specific intermittent and multidirectional running. These data extend previous research that identified good within-device reliability of PL_{VM} during mechanical perturbations of MEMS devices[22] and during treadmill running.[12] While further work is warranted to examine the between-matches variability of accelerometer metrics in team sports, the current data suggest that PL_{VM} and its triaxial planes may be useful tools to determine either real-time or chronic changes in external loading.

Practical Applications

PlayerLoad variables have moderate to high test–retest reliability and can be used to monitor athletes' external loading during intermittent and multidirectional running. Accelerometer data measured from MEMS devices positioned between the scapulae should be used with caution when attempting to determine changes in lower-limb movement strategy. Real-time monitoring of accelerometer data recorded at the COM identifies increases in loading possibly owing to fatigue or altered movement strategy, which may be used to inform external-load prescription or interchange/substitution policy in team-sport players.

Conclusions

PlayerLoad increased within each half of simulated soccer match play, despite players' performing repeated standardized 15-minute activity blocks in a laboratory controlled environment. This suggests that players' movement strategy becomes less efficient, which corresponds to previous observations of fatigue[17,18] and increased injury incidence[18,19] during the latter stages of each half. Since the accelerometer metrics were stable properties, real-time monitoring of PL_{VM} during training and match play may be a useful strategy to identify players' alterations in movement strategy. However, since within-match changes in accelerometer variables were specific to the positioning of the unit, we would suggest caution in making inferences regarding lower-limb kinematic changes when data are collected from scapula-mounted MEMS devices.

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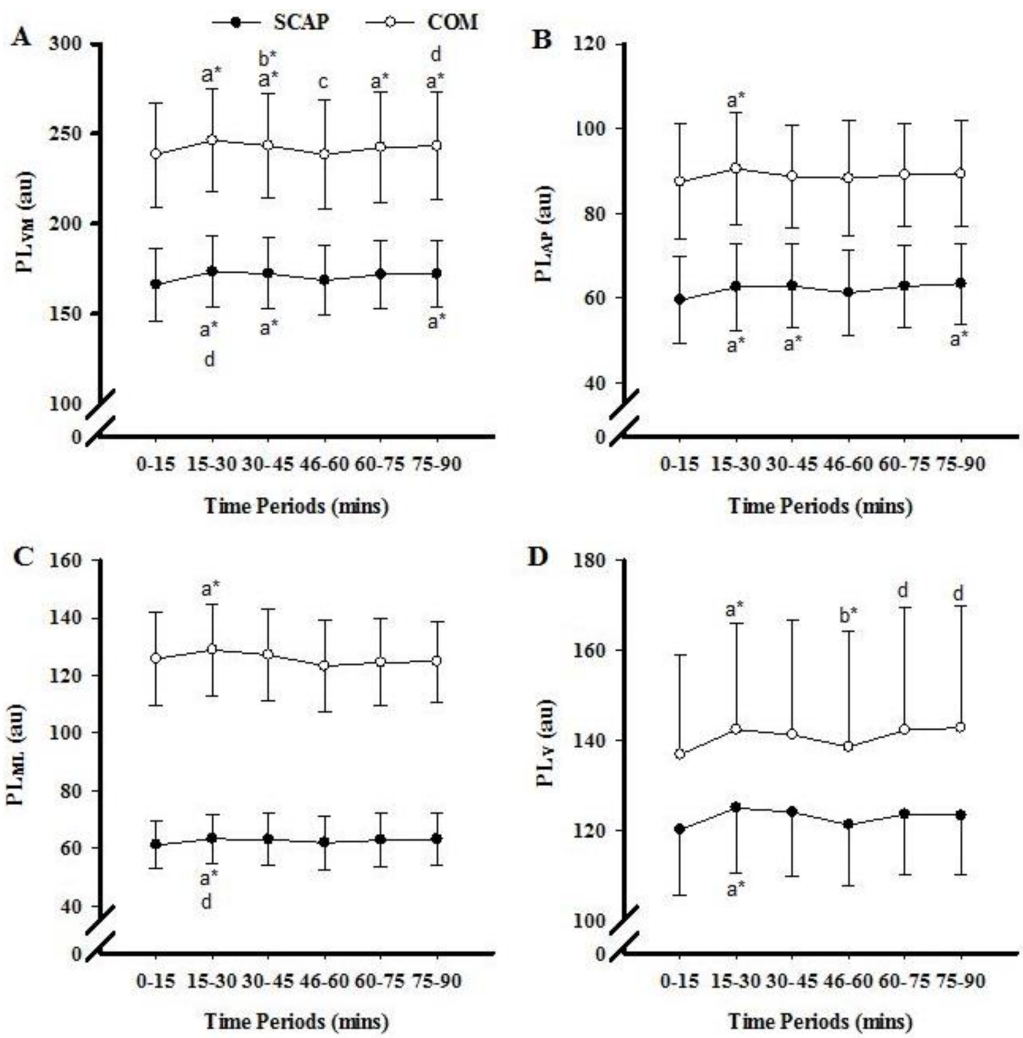

Figure 1 — Accelerometer data (PL_{VM} = A, PL_{AP} = B, PL_{ML} = C, PL_{V} = D) during SAFT[90] as measured at the scapulae (SCAP) and near the center of mass (COM). Abbreviations: PL_{VM}, PlayerLoad vector magnitude; PL_{AP}, PlayerLoad in the anteroposterior plane; PL_{ML}, PlayerLoad in the mediolateral plane; PL_{V}, PlayerLoad in the vertical plane. [a] Difference vs 0–15 min; [b] Difference vs 15–30 min; [c] Difference vs 30–45 min; [d] Difference vs 45–60 m. *Significant difference of $P \leq .01$.

Table 1 Test–Retest Reliability for the Triaxial Accelerometry Data Collected During SAFT^{90} at Both the Scapulae (SCAP) and Near the Center of Mass (COM)

Anatomical location		Trial 1	Trial 2	Change in mean (95% CI)	*P*	Effect size	ICC (95% CI)	CV (%)	Typical error (95% CI)
SCAP	PL_{VM}	1015 ± 116	1033 ± 110	–17 (–43 to 8)	.88	0.08	.94 (.84–.98)	3.8	15 (3–44)
	PL_{AP}	343 ± 69	347 ± 59	–4 (–24 to 15)	.80	0.03	.88 (.70–.95)	8.5	16 (2–45)
	PL_{ML}	349 ± 67	348 ± 56	1 (–8 to 10)	.96	0.01	.97 (.93–.99)	4.2	8 (1–25)
	PL_{V}	681 ± 127	695 ± 123	–14 (–28 to 0)	.97	0.06	.99 (.96–.99)	3.1	13 (1–33)
COM	PL_{VM}	1469 ± 182	1434 ± 163	35 (1 to 70)	.92	0.10	.95 (.88–.98)	3.6	33 (3–76)
	PL_{AP}	515 ± 108	491 ± 99	24 (–5 to 52)	.83	0.12	.90 (.76–.96)	8.7	22 (2–104)
	PL_{ML}	723 ± 129	702 ± 130	21 (–16 to 56)	.82	0.08	.90 (.75–.96)	7.7	24 (2–153)
	PL_{V}	819 ± 188	774 ± 185	45 (1 to 89)	.88	0.07	.94 (.83–.97)	4.9	28 (1–207)

Abbreviations: PL_{VM}, PlayerLoad vector magnitude; PL_{AP}, PlayerLoad in the anteroposterior plane; PL_{ML}, PlayerLoad in the mediolateral plane; PL_{V}, PlayerLoad in the vertical plane; ICC, intraclass correlations; CV, coefficient of variation; 95% CI, 95% confidence intervals.