Construct Validity and Test–Retest Reliability of Hip Load Compared With Playerload During Football-Specific Running, Kicking, and Jumping Tasks

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Purpose: To determine the test–retest reliability of the recently developed Hip Load metric, evaluate its construct validity, and assess the differences with Playerload during football-specific short-distance shuttle runs. Methods: Eleven amateur football players participated in 2 identical experimental sessions. Each session included 3 different shuttle runs that were performed at 2 pace-controlled running intensities. The runs consisted of only running, running combined with kicks, and running combined with jumps. Cumulative Playerload and Hip Loads of the preferred and nonpreferred kicking leg were collected for each shuttle run. Test–retest reliability was determined using intraclass correlations, coefficients of variation, and Bland–Altman analyses. To compare the load metrics with each other, they were normalized to their respective values obtained during a 54-m run at 9 km/h. Sensitivity of each load metric to running intensity, kicks, and jumps was assessed using separate linear mixed models. Results: Intraclass correlations were high for the Hip Loads of the preferred kicking leg (.91) and the nonpreferred kicking leg (.96) and moderate for the Playerload (.87). The effects (95% CIs) of intensity and kicks on the normalized Hip Load of the kicking leg (intensity: 0.95 to 1.50, kicks: 0.36 to 1.59) and nonkicking leg (intensity: 0.96 to 1.53, kicks: 0.06 to 1.34) were larger than on the normalized Playerload (intensity: 0.12 to 0.25, kicks: 0.22 to 0.53). Conclusions: The inclusion of Hip Load in training load quantification may help sport practitioners to better balance load and recovery.

Keywords: soccer, training load, inertial measurement units, biomechanical load, shuttle runs

Football players undergo high physical loads during training and matches.1 An appropriate balance between bouts of these high physical loads and recovery leads to beneficial physiological and biomechanical adaptations of the cardiovascular and musculoskeletal systems while, at the same time, injury risk is minimized.2 Adequate quantification of the player’s physical load can, therefore, help coaches, embedded scientists, and medical staff evaluate whether the intended physical load of their training program has been met to achieve greater adaptations and lower injury rates in their players.

When assessing physical loads endured by players, a distinction can be made between external and internal loads and between physiological loads and biomechanical loads.2 In football, external loads are defined by player activities on the field, whereas internal loads consider the individual’s response to these external loads. Physiological loads and adaptations concern cardiovascular and metabolic demands and the subsequent physiological adaptations, such as capillarization and increases in oxidative capacity. On the other hand, biomechanical loads concern stresses and strains on musculoskeletal tissues (ie, tendon force and musculotendon strain) leading to adaptations of mechanical properties, such as increases in fascicle length and tendon stiffness. These 2 types of physical load may have different adaptation rates, which have important consequences for adequate periodization of training bouts. Importantly, most injuries in football concern structural damage to joints, ligaments, tendons, and muscles,3,4 highlighting the importance of considering biomechanical loads and adaptations in load quantification.

Currently, metrics derived from player tracking systems worn at the trunk, such as Global Navigation Satellite Systems and local positioning measurement (LPM) devices, play a dominant role in quantifying physiological load of football players.1,5 Yet, these systems were not designed to quantify biomechanical load, and their accuracy is limited for measuring whole-body accelerations and decelerations.6 To get more insight in the biomechanical load, accelerometers are being incorporated in Global Navigation Satellite Systems and LPM systems, which allows for biomechanical load quantification with acceleration-based load metrics, such as Playerload (see Equation 3).7–9 However, a single accelerometer mounted at the trunk can only be used to estimate the biomechanical loads taken up by the body as a whole and does not provide detailed insights into the loads taken up by individual joints, muscles, or muscle groups.10 For example, a training session that includes many long-distance passes and free kicks does not necessarily impose great whole-body loads, but it does inflict high loads on the muscles around the hip.11,12 These high muscle loads would be missed by the current methods of load quantification. Moreover, the ability to quantify hip-specific external biomechanical load may be highly relevant considering that muscle injuries to
the thigh, groin, and hip account for about 22% of all injuries in professional football.

Net torques around a joint result in an angular acceleration of that joint. These net joint torques are primarily caused by external forces (ie, ground reaction forces), muscle contractions, ligaments, and other tissues crossing the joint. Therefore, our group developed a new metric to quantify hip joint-specific external biomechanical load called Hip Load. Hip Load is measured with 3 inertial measurement units (IMUs) worn at the pelvis and both thighs. These sensors measure 3D acceleration, 3D angular velocity, and 3D magnetic field strength and can be used to estimate joint angular accelerations. Hip Load is defined as the squared magnitude of the joint angular accelerations divided by a scale factor to improve readability (see Equation 2). As high-intensity activities demand more from musculoskeletal structures, angular accelerations are squared to give more weight to high-intensity movements in the load estimate. The results of a previous study by our group showed that Hip Load adds unique information to Playerload or other load estimates. The results of a previous study by our group showed that Hip Load adds unique information to Playerload or other load estimates. The results of a previous study by our group showed that Hip Load adds unique information to Playerload or other load estimates. The results of a previous study by our group showed that Hip Load adds unique information to Playerload or other load estimates. The results of a previous study by our group showed that Hip Load adds unique information to Playerload or other load estimates. The results of a previous study by our group showed that Hip Load adds unique information to Playerload or other load estimates. However, the test–retest reliability of Hip Load was not assessed. A good test–retest reliability is required to be able to compare multiple training sessions or matches with each other over time. However, a perfect test–retest reliability should not be expected due to factors such as variability in movement execution or differences in sensor placement and fixation. Moreover, the construct validity of Hip Load is not established yet. In other words, it remains unclear whether Hip Load distinguishes between different running intensities as well as between different exercise modalities, such as running, kicking, and jumping.

Therefore, the aims of present paper are to determine the test–retest reliability of Hip Load, evaluate the construct validity of Hip Load, and to assess the differences with the commonly used Playerload metric during football-specific shuttle runs performed at different running intensities. It was hypothesized that Hip Load is sensitive to running intensity and the type of task performed. This means that higher values were expected for high-intensity runs compared with low-intensity runs and for shuttle runs that included kicks and jumps compared with shuttle runs that involved only running. It was also expected that, compared with Playerload, Hip Load would be more sensitive to an increased load imposed by kicks, jumps, and increased running intensity.

Methods

Participants

Eleven trained amateur male football players (age, 21.3 [2.2] y; height, 184 [6] cm; weight, 84.2 [15.4] kg; and years of football experience, 13.3 [5.6] y) participated in the study. The sample of participants included 2 attackers, 5 midfielders, and 4 defenders. On average, the participants had 3.5 (1.8) hours of football-specific training or competitive matches per week. All participants were free of injuries at the time of testing. In addition, they were informed about the experimental procedures, and all signed consent before participation. Ethical approval was given by the scientific and ethics review board of the faculty of Behavioural and Movement Sciences of the Vrije Universiteit Amsterdam (VCWE-2019-070R1).

Data Acquisition

Participants were equipped with a commercially available Inmotio LPM system (version 5.1, Inmotio) that was used to measure player position on an outside artificial-turf football field. Participants wore a vest with 2 antennas on the shoulders and a small pocket between the scapulae, which contained the LPM transponder. Player position data were sampled at 1000 Hz divided by the number of LPM transponders (between 4 and 8).

In addition, participants wore six 9-degrees-of-freedom IMUs (MPU-9150, InvenSense), which were placed at the lower back, thighs, and shanks, according to procedures described previously and on the upper back in the same pocket as the LPM transponder. The other IMUs were fixed on the skin with double-sided adhesive tape. The lower back sensor was placed on the sacrum, the thigh sensors halfway on the iliotibial tract, and the shank sensors were placed halfway on the shin. IMU data were sampled at a frequency of 500 Hz and stored on a local SD card, which was embedded in a protective casing together with an SD card and a battery (size: 35 × 25 × 15 mm; total weight: 11 g). Before measurements, all IMUs were packed in a small box. The box was then tapped on a table to introduce a mechanical peak in the accelerometer signals, which was used to time synchronize the sensors.

Procedures

The study consisted of 2 identical experimental sessions on 2 separate days, which were 7 (1) days apart. Before each experimental session, participants performed a standardized warm-up that consisted of jogging, 3 running drills (butt kicks, side steps, and high knees), 2 football-specific movements (ball kicks and jumps), and straight runs with increasing speed. Thereafter, the participants performed two 16-m time synchronization runs. A mechanical timing gate with an additional attached time-synchronized IMU (as described elsewhere) was positioned at the 16-m mark together with 2 active LPM transponders placed to the sides, creating an “LPM-gate.” The 2 synchronization runs led to 2 moments of passage through this gate, which could be observed with both systems. The average time difference of the 2 passages through the gate measured by both systems was used to time synchronize the 2 measurement systems.

The main testing procedures started with three 54-m straight line normalization runs that were paced at 9 km/h using auditory beeps at cones placed every 9 m. These runs were used to compare the different load metrics with each other, which is further explained in the statistical analysis. Thereafter, a series of 3 different 6 × (7 + 2 m) shuttle runs were executed. Every type of shuttle run was performed 3 times at a low running intensity and 3 times at a high running intensity, leading to 6 shuttle run conditions: a low running intensity shuttle run, a high running intensity shuttle run, a low running intensity shuttle run with kicks, a high running intensity shuttle run with kicks, a low running intensity shuttle run with jumps, and a high running intensity shuttle run with jumps.

The first 7 m of each shuttle run was paced at either 9 km/h (2.5 m/s, low running intensity) or 14 km/h (approximately 3.9 m/s, high running intensity) using auditory beeps (at cones 1 and 3, or cones 4 and 2; see Figure 1), whereas the last 2 m was used as a runoff during which participants could decelerate and make a 180° turn. The 2-m runoff had a fixed duration of 2 seconds before the next beep sounded and participants started the return run, which was paced in the same manner. Based on extensive pilot testing, the high running intensity was chosen such that it was just attainable when kicks and jumps were included in the shuttle runs for most players. The kicks and jumps were performed at the 7-m mark (depending on the movement direction at cone 3 or cone 2; see
Figure 1 — Schematic representation of \(6 \times (7 + 2\) m) shuttle runs. The shuttle runs were paced with auditory beeps at cones 1 to 4. The first 7 m of each way was paced at a mean running speed of 9 km/h (2.5 m/s, low intensity) or 14 km/h (approximately 3.9 m/s, high intensity). Kicks and jumps were performed on the auditory beep at either cone 3 (when running from left to right) or at cone 2 on the way back (return run from right to left).

Figure 1) on the sound of the beep. Participants were instructed to maximally kick the ball into the goal located at a 6-m distance when kicks were included in the shuttle runs. In addition, participants were instructed to always kick the ball with their preferred kicking leg. All kicks and jumps were performed at maximal intensity, irrespective of the paced running intensity. The first trial of each shuttle run (type and running intensity) was used for familiarization, and the second and third were used for data collection.

Data Processing

**Hip Load.** Hip Load is expressed in arbitrary units and is the squared magnitude of the joint angular acceleration of the hip \(\omega_{\text{hip}}\) divided by a scale factor to improve readability:

\[
\text{Hip Load} = \frac{|\omega_{\text{hip}}|^2}{10^6} \tag{1}
\]

The IMUs on the thighs and lower back were used to calculate the Hip Load of both hips. The orientation of each IMU was continuously estimated using a Madgwick gradient descent filter with filter gain \(\beta\) set to 0.043 as recommended for dynamic measurements.\(^{20}\) The IMU orientations were then used to express angular velocity measurements of each IMU in the earth-fixed global reference frame. In this way, the angular velocity of the hips could be obtained by subtracting the 3D angular velocity of each thigh from the 3D angular velocity of the lower back:

\[
\omega_{\text{hip}} = \omega_{\text{lower back}} - \omega_{\text{high}} \tag{2}
\]

The angular velocities were then differentiated to obtain the 3D angular acceleration of both hips. Thereafter, the instantaneous Hip Loads were calculated using Equation 1. For each exercise, the Hip Loads were integrated to obtain the cumulative Hip Loads per exercise (ie, the total Hip Loads per \(6 \times (7 + 2\) m) shuttle run). Hip Loads were calculated for the preferred kicking leg (Hip Load kick) and for the nonpreferred kicking leg (Hip Load nonkick) to be able to differentiate between the effects of kicking on the Hip Load of the stance leg or of the kicking leg.

The same data processing steps were performed using the IMUs on the shanks and thighs to obtain the joint-specific loads of the knees (Knee Load kick and Knee Load nonkick). These results can be found in the Supplementary Material (available online). We chose not to present those in the main paper for clarity because we observed similar results and because we foresee only shorts being used in football practice and not long tights.

**Playerload.** The Playerload was collected using the IMU located between the scapulae. First, the linear acceleration data were filtered using a zero-lag fourth-order low-pass Butterworth filter with a cutoff frequency of 10 Hz.\(^{14}\) Thereafter, the instantaneous Playerload was calculated using the following formula:\(^{8}\)

\[
\text{Playerload} = \frac{\sqrt{(a_{x,t}-a_{x,t-1})^2 + (a_{y,t}-a_{y,t-1})^2 + (a_{z,t}-a_{z,t-1})^2}}{100} \tag{3}
\]

The instantaneous Playerload was integrated to obtain the cumulative Playerload of each exercise (ie, the total load per \(6 \times (7 + 2\) m) shuttle run). It should be noted that acceleration filter methods are generally not presented\(^{7,8}\); therefore, results may slightly differ from other studies.

**Local Positioning Measurement.** The LPM data were filtered (integrated “weighted Gaussian average” filter set at 85% as recommended by the manufacturer) and resampled to 50 Hz using Inmotio software (version v6.2.0.383, Inmotio). To validate the experimental procedures, total distance and average running speed were collected, which included the 2-second runoffs of the shuttle runs.

Statistical Analysis

For all exercises, the average cumulative loads of the second and third trial of each experimental session were used for the statistical analyses. Test–retest reliability assessment was based on the load metrics across all different exercises between the first and second experimental session. Test–retest reliability was assessed using coefficients of variation (CV), intraclass correlation (ICC[3,1]),\(^{21}\) and Bland–Altman analysis with 95% limits of agreement. ICCs were interpreted as high (>0.90), moderate (0.80–0.89), or questionable (<0.80).\(^{22}\)

Because Hip Load and Playerload are expressed in arbitrary units, their absolute values cannot be directly compared. Therefore, all cumulative Hip Load and Playerload metrics were normalized by dividing each cumulative load metric by its respective value obtained during the 54-m normalization runs before direct comparison. Thereafter, the effects of intensity, kicks, jumps, and experimental session on each load metric were quantified with a separate linear mixed model for each load metric using the “nlme” package\(^{23}\) in R (version 4.0.3).\(^{24}\) The models included intensity,
kicks, jumps, and experimental session as main fixed factors as well as fixed interaction terms between intensity and kicks and between intensity and jumps. In addition, random intercepts for participants were included to control for the dependency between conditions. The magnitudes, 95% confidence intervals, and P values are reported for each effect. In addition, differences between the normalized Hip Loads and normalized Playerload were separately assessed for each exercise using pairwise t tests with a Bonferroni correction. Results were deemed significant with P < .05.

Results

The nonnormalized load metrics of the $6 \times (7 + 2 \ m)$ shuttle runs are summarized in Table 1. Note that the average running speed during the low running intensity shuttle runs was lower than for the straight-line normalization runs. The reason for this is that only the first 7 m of each shuttle was paced followed by 2-m runoff that took 2 seconds, leading to a lower average running speed. CVs and ICCs related to the test–retest reliability were relatively high for Hip Load kick and Hip Load nonkick (Figure 2). The ICC of Playerload was slightly lower and so was the CV (Figure 2).

Results of the separate (one for each load metric) linear mixed models are shown in Table 2. In addition, the normalized Hip Loads and Playerload are shown in Figure 3. There were significant main effects of intensity, kicks, and jumps on all load metrics as well as a significant interaction effect between intensity and jumps (Table 2).

Discussion

The aims of the present paper were to evaluate the test–retest reliability of the recently developed Hip Load, to assess the construct validity of Hip Load (ie, whether Hip Load is sensitive to different running intensities and exercise modalities), and to assess the differences with the commonly used Playerload. This was investigated with football-specific short-distance shuttle runs. Acceptable to good test–retest reliability was found for the Hip Load and Playerload. Furthermore, significant effects of kicks, jumps, and running intensity on the Hip Load of the preferred kicking leg and on the Hip Load of the nonpreferred kicking leg during the football-specific shuttle runs were demonstrated. Moreover, the Hip Loads of the preferred kicking leg and the nonpreferred kicking leg were more sensitive to increases in running intensity and to kicks compared with Playerload.

The ICCs were high for the Hip Loads of the preferred kicking leg and the nonpreferred kicking leg, indicating a good test–retest reliability. However, the CV and 95% limits of agreement were relatively large for the Hip Load of the preferred kicking leg. A potential reason is that Hip Load is sensitive to small differences in movement execution, especially during movements that involve large hip angular accelerations (eg, kicking). Because Hip Load is the squared magnitude of the hip angular acceleration, differences in peak angular accelerations are magnified. Nevertheless, this could also be seen as a strength of the Hip Load metric because movements performed at a high intensity may be most relevant for injury incidence. In addition, despite careful standardization of sensor placement and fixation, small differences therein between sessions could have led to increases in the CVs. There was one participant (Figure 2 top right Bland and Altman plot) who might have executed the movements differently between sessions, thereby increasing the CV of the Hip Loads. The ICC and CV of the Playerload were comparable with previous findings. The acceptable to good test–retest reliability of Hip Load in the present study supports its use for monitoring and comparing external hip-specific biomechanical load over time and between training sessions and matches.

The linear mixed models revealed significant effects of running intensity on the normalized cumulative Hip Load values (Table 2). Cumulative Hip Load of the preferred kicking leg and of the nonpreferred kicking leg, respectively, were 60% and 62% higher during the high compared with the low running intensity shuttle runs (Table 1), whereas the average running speed showed an increase of about 36% (Table 1). This may seem like an overestimation of the external biomechanical load resulting from increases in running speed. However, it should be noted that the high running intensity shuttle runs required not only a higher average running speed but also higher acceleration and deceleration demands, which would likely necessitate larger angular accelerations of the hips. Therefore, we conclude that Hip Load is an appropriate metric to detect differences in running intensity. In contrast, Playerload showed a relative increase of only 7% (Table 1) between the low- and high-intensity shuttle runs that was considerably smaller than the relative increase in average running speed (36%; Table 1), suggesting that Playerload underestimates the

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Hip Load kick, AU</th>
<th>Hip Load nonkick, AU</th>
<th>Playerload, AU</th>
<th>Total distance, m</th>
<th>Average running speed, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norm run (54 m)</td>
<td>31 (11)</td>
<td>31 (10)</td>
<td>4.0 (0.8)</td>
<td>54.1 (0.3)</td>
<td>2.4 (0.1)</td>
</tr>
<tr>
<td>LI</td>
<td>42 (15)</td>
<td>42 (14)</td>
<td>4.9 (0.8)</td>
<td>58.0 (4.7)</td>
<td>1.9 (0.2)</td>
</tr>
<tr>
<td>HI</td>
<td>81 (36)</td>
<td>80 (33)</td>
<td>5.6 (0.9)</td>
<td>61.9 (4.8)</td>
<td>2.7 (0.2)</td>
</tr>
<tr>
<td>LI + kick</td>
<td>66 (20)</td>
<td>50 (18)</td>
<td>6.1 (0.9)</td>
<td>60.2 (5.1)</td>
<td>2.0 (0.2)</td>
</tr>
<tr>
<td>HI + kick</td>
<td>100 (36)</td>
<td>82 (34)</td>
<td>6.5 (1.0)</td>
<td>64.5 (5.4)</td>
<td>2.8 (0.2)</td>
</tr>
<tr>
<td>LI + jump</td>
<td>51 (17)</td>
<td>52 (18)</td>
<td>6.4 (1.0)</td>
<td>56.5 (4.5)</td>
<td>1.9 (0.2)</td>
</tr>
<tr>
<td>HI + jump</td>
<td>73 (23)</td>
<td>71 (25)</td>
<td>6.5 (0.8)</td>
<td>55.2 (5.2)</td>
<td>2.4 (0.3)</td>
</tr>
</tbody>
</table>

Abbreviations: AU, arbitrary units; HI, $6 \times (7 + 2 \ m)$ high intensity; HI + kick, $6 \times (7 + 2 \ m)$ high intensity with kicks; HI + jump, $6 \times (7 + 2 \ m)$ high intensity with jumps; HI + kick, $6 \times (7 + 2 \ m)$ high intensity with kicks; Hip Load kick, Hip Load preferred kicking leg; Hip Load nonkick, Hip Load nonpreferred kicking leg; LI, $6 \times (7 + 2 \ m)$ low intensity; LI + jump, $6 \times (7 + 2 \ m)$ low intensity with jumps; LI + kick, $6 \times (7 + 2 \ m)$ low intensity with kicks; norm run, $54$-m normalization run. Note: The values are presented as mean (SD).
additional training load. This finding concurs with those of Barret et al., who reported Playerload values at different running speeds on an instrumented treadmill. When the treadmill speed increased by 55% from 9 to 14 km/h, the distance run per minute also increased by 55% from 150 to 233 m, but Playerload per minute only increased by 35%. This means that if they would have expressed the Playerload per meter covered, its value would decrease by 13% when running speed increased from 9 to

Figure 2 — Bland–Altman plots of Hip Load kick, Hip Load nonkick, and Playerload. The dashed line in the left figures shows the line of equality between both experimental sessions. In the right plots, the dashed line shows the bias, the continuous lines show the upper and lower limits of agreement (±1.96 SD), and the dotted lines show the 95% CIs of the limits of agreement. In addition, each shade of gray represents 1 participant, the circles represent the 6×(7 + 2 m) shuttle runs without kicks or jumps, the squares represent the 6×(7 + 2 m) shuttle runs with kicks, and the diamonds represent the 6×(7 + 2 m) shuttle runs with jumps. Furthermore, the open figures represent the 6×(7 + 2 m) shuttle runs performed at a low running intensity, whereas the closed figures represent the 6×(7 + 2 m) shuttle runs performed at a high running intensity. CV indicates coefficients of variation; Hip Load kick, Hip Load of the preferred kicking leg; Hip Load nonkick, Hip Load of the nonpreferred kicking leg; ICC, intraclass correlations.
14 km/h. Thus, when an athlete runs the same distance at a higher speed, the cumulative Playerload will be lower than when the same distance is run at a lower speed. Therefore, we argue that Hip Load is more suitable to quantify increases in biomechanical loads resulting from increases in running intensity compared with Playerload.

Kicks showed significant effects on the normalized Hip Loads of the preferred and the nonpreferred kicking leg. To maximally kick a ball, the kinetic energy that a player carries needs to be transferred to the ball as efficiently as possible.25 This involves large angular accelerations and decelerations of the hip, which explains the high Hip Load values of the preferred kicking leg for the shuttle runs that included kicks. As the support leg has the function to decelerate the player,26 it is not surprising that the support leg also contributed to the significant effect of kicks on Playerload. In an attempt to keep up with the pace required at the high running intensity shuttle runs when jumps were included, some participants showed nonmaximal jumping efforts, which contributed to the interaction effects between running intensity and jumps found for all load metrics (ie, the effects of jumps being smaller for the high running intensity shuttle runs).

A limitation of present study is that kicks and jumps were always performed at maximal intensity. Differences in execution intensity of these movements may lead to differences in Hip Load values. Kicking or jumping at reduced intensities requires lower joint accelerations and will most likely reduce Hip Loads. Another limitation is that there are no gold standard methods for quantifying biomechanical loads on the field. As a solution, the experiment was designed such that the physiological load variables (ie, total distance and average running speed) were kept constant between the different shuttle runs but that the amount of movement was increased when jumps and kicks were included. Therefore, the biomechanical load of these shuttle runs must have been higher than the ones that included running only. Furthermore, these results

### Table 2 Results of the Linear Mixed Models Hip Load of the Preferred Kicking Leg, Hip Load of the Nonpreferred Kicking Leg, and Playerload

<table>
<thead>
<tr>
<th>Effects linear mixed models</th>
<th>Hip Load kick</th>
<th>Hip Load nonkick</th>
<th>Playerload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td>1.23</td>
<td>1.25</td>
<td>0.18</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.95 to 1.50</td>
<td>0.96 to 1.53</td>
<td>0.12 to 0.25</td>
</tr>
<tr>
<td>P</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Kick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td>0.98</td>
<td>0.70</td>
<td>0.38</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.36 to 1.59</td>
<td>0.06 to 1.34</td>
<td>0.22 to 0.53</td>
</tr>
<tr>
<td>P</td>
<td>.003</td>
<td>.035</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Jump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td>0.76</td>
<td>0.86</td>
<td>0.53</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.14 to 1.37</td>
<td>0.23 to 1.50</td>
<td>0.38 to 0.69</td>
</tr>
<tr>
<td>P</td>
<td>.020</td>
<td>.010</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Experimental session</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td>−0.22</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>95% CI</td>
<td>−0.38 to −0.06</td>
<td>−0.16 to 0.16</td>
<td>−0.04 to 0.04</td>
</tr>
<tr>
<td>P</td>
<td>.008</td>
<td>.998</td>
<td>.969</td>
</tr>
<tr>
<td>Intensity × kick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td>−0.13</td>
<td>−0.17</td>
<td>−0.08</td>
</tr>
<tr>
<td>95% CI</td>
<td>−0.52 to 0.26</td>
<td>−0.57 to 0.23</td>
<td>−0.17 to 0.02</td>
</tr>
<tr>
<td>P</td>
<td>.521</td>
<td>.409</td>
<td>.136</td>
</tr>
<tr>
<td>Intensity × jump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td>−0.46</td>
<td>−0.55</td>
<td>−0.15</td>
</tr>
<tr>
<td>95% CI</td>
<td>−0.85 to −0.07</td>
<td>−0.95 to −0.15</td>
<td>−0.24 to −0.05</td>
</tr>
<tr>
<td>P</td>
<td>.026</td>
<td>.009</td>
<td>.005</td>
</tr>
</tbody>
</table>

Abbreviations: Hip Load kick, Hip Load of the preferred kicking leg; Hip Load nonkick, Hip Load of the nonpreferred kicking leg. Note: The “×” denotes the interaction between terms.
were obtained from amateur football players, but it remains unclear whether the new external biomechanical load metrics discriminate between other levels of play. Moreover, using separate IMUs is impractical during regular training sessions or competition. However, we are working on the integration of the IMUs and electronics in the clothing of football players, which makes the method feasible in daily practice.

**Practical Implications**

This study substantiates the use of Hip Load above whole-body Playerload to quantify external biomechanical load in football practice. The effects of kicks and jumps show that Hip Load can detect the additional hip-specific external biomechanical loads of these movements. Moreover, compared with Playerload, Hip Load is probably more closely related to the biomechanical loads on the musculoskeletal tissues that are highly involved during football. Therefore, the inclusion of Hip Load may improve training load quantification, which would help sport practitioners to better balance load and recovery to prevent overload and potentially reduce injury incidence.

**Conclusions and Recommendations**

This study makes several noteworthy contributions to the field of training load quantification in football. Additional evidence was provided with respect to the reliability and validity of Hip Load as an external biomechanical training load metric. First, good test–retest was shown, which enables comparison between training sessions or matches. Second, Hip Load can quantify additional hip-specific load of football kicks and jumps. Third, Hip Load is more sensitive to differences in running intensity than the commonly used Playerload. Further studies are required to establish the potential relationship between Hip Load and injury incidence.

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