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Barreira, P, Robinson, MA, Drust, B, Nedergaard, NJ, Raja Azidin, RM and Vanrenterghem, J (2016) Mechanical Player Load™ using trunk-mounted accelerometry in football: Is it a reliable, task- and player-specific observation? Journal of Sports Sciences. ISSN 1466-447X

Mechanical Player Load^{TM} using trunk mounted accelerometry in Football: Is it a reliable, task- and player-specific observation?

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Journal of Sport and Exercise Sciences

http://dx.doi.org/10.1080/02640414.2016.1229015

Abstract

The aim of the present study was to examine reliability and construct convergent validity of Player Load™ (PL) from trunk-mounted accelerometry, expressed as a cumulative measure and an intensity measure (PL · min^{-1}). Fifteen male participants twice performed an overground football match simulation that included four different multidirectional football actions (jog, side cut, stride and sprint) whilst wearing a trunk-mounted accelerometer inbuilt in a global positioning system unit. Results showed a moderate-to-high reliability as indicated by the intra-class correlation coefficient (0.806–0.949) and limits of agreement. Convergent validity analysis showed considerable between-participant variation (coefficient of variation range 14.5–24.5%), which was not explained from participant demographics despite a negative association with body height for the stride task. Between-task variations generally showed a moderate correlation between ranking of participants for PL (0.593–0.764) and PL · min^{-1} (0.282–0.736). It was concluded that monitoring PL in football multidirectional actions presents moderate-to-high reliability, that between-participant variability most likely relies on the individual's locomotive skills and not their anthropometrics, and that the intensity of a task expressed by PL · min^{-1} is largely related to the running velocity of the task.

Keywords**:** accelerometry, football, validity, reliability.

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Introduction

Accelerations and decelerations constitute an essential element of football, particularly in sprint actions or short changes of direction such as side cutting or dribbling (Bloomfield, Polman & O´Dononghue, 2007; Varley & Aughey, 2013). The high accelerations and decelerations are known to lead to high forces acting on the musculoskeletal system which in turn need to be absorbed by internal musculoskeletal structures (Bobbert, Schamhardt, & Nick, 1991). It is possible that the magnitude of these forces can directly exceed the body's capacity to absorb their impact and lead to acute tissue damage (e.g. bone fracture, muscle strain, ligament tear), but the excessive exposure to moderate yet repetitive forces can also exceed the body's capacity to recover from small (micro) damage, eventually leading to macro damage (e.g. stress fractures, cartilage degeneration).

Monitoring acceleration and deceleration loads through the use of accelerometers embedded in the commonly used trunk mounted Global Positioning System (GPS) units may help understand the association between the forces due to excessive loading on the football player´s musculoskeletal tissues, and assist in injury risk profiling. This monitoring is based on the impact that the absorption of ground reaction forces may have on the football player´s body (Ehrmann, Duncan, Sindhuase, Franzen, & Greene, 2015; Colby, Dawson, Heasman, Rogalski, & Gabbet, 2014), and whilst showing some promising results from the way accumulated accelerometry based loads per week can relate to injury risk (Colby et al., 2014), a number of unknowns regarding validity and reliability around accelerometry monitoring still remain. To date, accelerations and decelerations have often been expressed using Player Load ^{TM} (PL), a cumulative measure of rate of change in acceleration (Boyd, Ball, & Aughey, 2011).

The reliability of PL has been addressed in the recent literature. The laboratorial setup from Boyd et al. (2011) used a hydraulic testing machine and showed good reliability for accelerometry data collected in these conditions. Kelly, Murphy, Watsford, Austin, and Rennie (2015) also found a good inter and intra-device reliability when assessing raw accelerometer data using a laboratorial setup with mechanical rotation device. Barret, Midgley, and Lovell (2014) investigated an incremental treadmill running protocol with speeds ranging from 7 to 16 Km.h^{-1}, showed high test-retest reliability for PL, but between- subject PL scores were subject to individual running style variations. Recently, multi-directional running movements were investigated (Barret et al. 2015) which adopted a soccer-specific free-running match simulation (SAFT^{90}). Their test – retest results suggested high intra-device reliability, an absence of systematic bias, and low coefficients of variation. Despite this work, there are still some unknowns related to PL reliability. For example, reliability of PL for movements in isolation has not been addressed to date. The analysis involving multidirectional movements from Barret et al. (2015) considered total cumulative scores and did not isolate efforts such as sprinting, striding or side cutting. Analysing PL reliability of movements in isolation avoids potential bias from contamination of the acceleration signal loads from other movements or gestures when reliability of cumulative PL is analysed. Also, due to the cumulative nature of PL over time, it fails to represent the mechanical intensity of a movement and is unsuitable for distinguishing the impact that different actions have on a player during football. Expressing PL per unit of time (PL.min^{-1}) can therefore help indicate the rate of stress to which the player subjects their body for a given time period. By having representative intensity PL values for given movements a more meaningful insight into the mechanical stresses that these movements impose on the body can be gained.

Besides reliability, another issue that still deserves further clarification is the construct convergent validity of Player Load^{TM}, namely, how it is expected to vary between players, for example based on their body sizes. Player characteristics such as body mass influence the development of ground reaction forces (Derrick, Caldwell, & Hamill, 2000; Silder, Besier, & Delp, 2015), yet it is still unknown how PL is affected. For example, if an entire squad were to undergo the same training session, then it is important to know whether PL is expected to be the same or whether it will differ between players based on their body size.

The aim of this study was to improve our understanding of reliability and construct convergent validity of PL from trunk mounted accelerometry, expressed as a cumulative measure (PL) and as an intensity measure (PL.min^{-1}), across different multidirectional football actions. We considered the effects of the intensity level and duration of the action, as well as the subjects´ anthropometrics.

Methods

Fifteen male participants (25.8 ± 4.3 years; 1.79 ± 0.10 m; 77.3 ± 10.4 kg) were recruited for this study. All participants were recreational level athletes used to football practice and were free from any injury at the time of the study. Informed consent was obtained prior to participation in the study. The study met the requirements of the Liverpool John Moores University ethics committee and approval was obtained prior to the commencement of the study.

An overground match simulation protocol (SAFT^{90}) was modified from its original distance of 20 meters to 15 meters to fit our indoor laboratory (Azidin, Sankey, Drust, Robinson, & Vanrenterghem, 2015). The SAFT^{90} was designed to be reflective of the multidirectional nature of the specific movements of football, including frequent accelerations and decelerations. The movement intensity and activity performed by the participants whilst completing the overground course was maintained using verbal signals on an audio track, and contact actions such as kicking or tackling were not performed (Lovell, Knapper, & Small, 2008). Course design was based around a shuttle run over a 15 m distance, incorporating four positioned poles for the participants to navigate using multidirectional utility movements (Figure 1).

All participants first attended a familiarization session which was not recorded, followed by two data collection sessions separated by a minimum of three days. For data collection purposes each subject wore a trunk mounted GPS unit (Viper model, Statsports Technologies, USA), which had an in-built tri-axial 100 Hz accelerometer (ADXL 326, Analog Devices, Norwood, USA). The participants completed 45 minutes of the simulation protocol and the middle 15 minutes accelerometry data was used for analysis. This provided sufficient data on each of the observed tasks (see table 1), and minimized variations in outcome measures due to early adaptation with the protocol in the first 15 minutes of the protocol. Also, the interference of fatigue due to prolonged exercise in the performance of the protocol was avoided, as fatigue effects had been observed in the latter stages of each half for this type of simulation protocols (Barret et al., 2015; Marshall, Lovell, Jeppesen, Andersen, & Siegler, 2014).

Accelerometer data was downloaded in raw format from the manufacturer software (Viper, Statsports Technologies, USA), and a custom Matlab programme (Version R2014a, The MathWorks, Inc., Natick, MA, USA) was used to identify and select data to be included in the analysis. An interactive Graphical User Interface (GUI) was developed to verify the exact timing of transitions between tasks (see Figure 2). Start and end point identification of each task based on its time measure was adjusted by the same researcher. Due to the contributions of every action present in this protocol to the final cumulative PL score, in the present study data was isolated and analysed for each of four actions: jog, side cut, stride and sprint (see Table 1). These four tasks implied higher demands of acceleration and deceleration, for which walking and standing periods were excluded from the analysis. By eliminating the contribution of accelerometry data from these two actions in the final PL score and isolating the data from jogging, side cutting, striding and sprinting, one could more accurately analyse the reliability of PL in these tasks. The software calculated PL as the square root of the sum of the instantaneous rate of change in acceleration and deceleration (Boyd et al., 2011), as well PL.min^{-1} by dividing PL by the exact time spent executing a task.

Statistics

Within subject reliability analysis was performed first. Mean differences between test and re-test (systematic bias) were analysed using Student´s t-tests for paired samples, with a level of significance set as $p < 0.05$. Limits of agreement (LOA) for absolute reliability were also calculated according to the recommendations of Atkinson and Nevill (1998) and expressed in the form of Bland-Altman plots. Relative reliability to verify consistency of measurements between trials was assessed using two-way random intra-class correlation coefficient (ICC), in which scores were categorized as high (>0.90), moderate (0.80-0.89), or questionable (<0.80) (Hopkins, 2000).

Trial 2 results were used for the construct convergent validity analysis. Convergent validity was evaluated through within-subject variation in PL and PL.min^{-1} using coefficient of variation (CV), followed by Pearson´s association measures to verify the association between accelerometry scores of each task and measures of body mass, height and BMI. Comparisons across all tasks were performed using ANOVA for repeated samples, and Student´s t-tests were used to identify the pairs of tasks for each variable where a statistically significant difference was present.

Spearman´s rank correlations were calculated to verify the consistency of the subjects' ranking of accelerometry scores for each of the four tasks.

All statistical procedures were conducted using Statistical Package for the Social Sciences (SPSS, version 20.0, SPSS Inc., Chicago, IL, USA).

Results

Reliability analysis

Table 2 expresses results for trial 1 and 2 regarding PL and PL.min^{-1} SAFT^{90} 15-30 minutes scores. Paired Student´s t-tests showed an isolated small systematic bias for the jogging task when PL.min^{-1} scores are considered ($p < 0.05$). Moderate to high correlations between both trials were found across all tasks.

Bland-Altman LOA distribution of scores showed an overall good absolute reliability for the PL and PL.min^{-1} variables (Figure 3). The magnitude of the limits around the systematic bias were acceptable considering the average scores in each task, ranging from 17% to 41% relative to the average accelerometry scores. There were also variations according to the nature of the task being performed, with a trend towards reduced differences in tasks involving higher acceleration and deceleration demands. For the stride task this variation was 39% and 41% for PL and PL.min $^{-1}$ scores respectively, whereas in the sprint task PL and PL.min^{-1} scores presented variations of 17% and 28%, respectively.

Construct convergent validity analysis

Between-participant CV across each task showed more considerable variation, with the highest value registered in the stride task (24.5%) and the lowest corresponding to jogging (14.5%). No significant association was found between body mass and BMI on the one hand and PL or PL.min^{-1} scores on the other hand. Height explained between-participant variation for the stride task presenting a significant moderate negative association for PL (r^2= -0.611, p = 0.008) and PL.min^{-1} (r^2= - 0.482, p = 0.034) results.

Results for each participant showed different variations between tasks on trial 2 depending on whether the total accumulated PL or its intensity expression (PL.min^{-1}) was considered (Figure 4). Spearman´s correlation measures showed a significant moderate correlation between ranking of participants´ scores between tasks for PL (0.593-0.764) and PL.min^{-1} (0.282-0.736), except between the stride and the sprint tasks for expressions of PL intensity where no association was found. Comparisons between tasks (see table 3) using ANOVA for repeated samples showed significant differences for PL and PL.min^{-1} results. Paired sample student t-tests showed significant differences between all tasks, except between side cut and stride PL.min^{-1} (p= 0.239).

Discussion

PL and PL.min^{-1} relative to multidirectional football tasks, performed at different intensity levels, from regular jogging to maximal sprinting, present moderate to high reliability. The construct convergent validity analysis identified variations in PL and PL.min^{-1} between participants, with a small to moderate negative association between height and both PL and PL.min^{-1} in the stride task. The analysis of accelerometry scores between the four actions performed in this study identified significant differences for PL scores between all the tasks, which were only noticed between jogging and sprinting and the remaining tasks in the case of PL.min^{-1}, showing that when considering intensity, the speed of the task may play a relevant role in accelerometry scores.

Despite differences in protocol with previous studies, our test-retest reliability analysis were in agreement, showing a moderate to high relative reliability, with ICC scores ranging from 0.806 to 0.949 (Barret et al., 2015; Barret et al., 2014), and a good absolute reliability with acceptable LOA. This generally agrees with the existing PL reliability research using distinct protocols such as the SAFT^{90} (Barret et al.,2015), treadmill running (Barret et al., 2014), and mechanical or outfield setups (Boyd et al., 2011). A small systematic bias was found (p = 0.043) in the PL.min^{-1} for the jogging task. This could be attributed to a familiarization effect between trials related to running economy. The 29 repetitions of the jogging task were designated to be performed at the same pace and duration for the two tasks. Therefore, the observed decrease in the score for the PL intensity may be attributed to the fact that participants systematically started to run more economically in the second trial. Regarding the use of simulation protocols such as the SAFT^{90}, a low CV for within-subject comparisons was found for the accelerometry data collected during the 90 minutes of the protocol in a recent study (Barret et al., 2015).

Regarding construct convergent validity, our findings indicate that from the participants’ demographics only height presented a negative association with accelerometry in the stride task. The effect found (0.046) only marginally exceeded the level of significance adopted (0.05), and the absence of any other significant finding relating height with the remaining accelerometry scores may attribute it to a type I error. However, the fact that taller subjects presented lower PL and PL.min^{-1} scores may result from the less vertical displacements that the trunk mounted accelerometer would be subject to if the strategy to reach the target speed in the straight line stride task from the taller subjects consisted of increasing the stride length. Consequently this increase in stride length would be followed by an overall reduction in the shock wave from the foot contacts (Mercer, Devita, Derrick, & Bates, 2003). The association between body height and accelerations was not noticed in the sprint task where an increase in stride frequency is expected instead of stride length, the common strategy to raise velocity above the 25.2 km.h^{-1} threshold (Schache, Dorn, Williams, Brown, & Pandy, 2014). Regarding the side cut task, with a speed similar to the stride task (15 km.h^{-1}), the fact that a direction change was established within a short distance after the start of the task this may have led the subject to adopt a shorter stride length again in order to prepare the side cut on its designated location, hence changing the acceleration patterns accordingly. However, this line of reasoning is highly hypothetical and we believe that for this explanation to explain our results further detailed biomechanical analysis of stride characteristics would need to reveal if there is an actual alteration during striding in taller athletes which induces an observable change in trunk accelerations.

Subjects´ body mass did not influence PL or PL.min^{-1}, which may be a surprise. However, in order for the subjects to achieve target speeds due to the pre-established time and space of execution for each task, low variation between participants in the acceleration and deceleration efforts was expected. The aim of trunk mounted accelerometry is to provide an estimation of the ground reaction forces acting on the subject´s body (Wundersitz, Netto, Aisbett, & Gastin, 2013). Hence in order to maintain a similar accelerometry pattern between them, subjects with higher body mass have to apply more force than less heavy ones. Therefore, despite heavier individuals not having greater PL or PL.min^{-1}, the consequent mechanical loads on their musculoskeletal structures are expected to be higher. In summary, effects of anthropometrics on the acceleration and deceleration scores were negligible, despite the significant variation found between subjects for each task, confirmed by the high CV scores. Therefore this variation seems to be dependent on the individual´s biomechanical strategy for propelling their body depending on the action under performance. Factors such as increased stride lengths, increased hip, knee and ankle flexion ranges of motion, and longer stance times have been associated with increases in ground reaction forces during running (Silder et al., 2015; Mercer, Bezodis, Russell, Purdy, & DeLion, 2005; Mercer et al., 2003; Derrick, Hamill, & Caldwell, 1998), and we assume that our observed inter-individual variations are the consequence of such factors, rather than the differences in demographics.

Differences between accelerometry scores for four different tasks were analysed, either as a cumulative variable (PL) or an expression of intensity (PL.min^{-1}). The analysis of intensity showed differences between jogging and sprinting with the remaining tasks, whilst side cut and striding revealed no differences between them. This may be justified by the same target speed adopted (15 km.h^{-1}) during the protocol in the latter two efforts. It is interesting to notice that despite side cut and striding actions being constituted by efforts with different types of gestures in this protocol, such as up stride and side stride preliminary to the side cut action itself and a straight line effort for the stride task, this did not show to have an effect on PL intensity. Thus, the target speed to reach whilst performing the efforts seems to have been the key factor contributing to it. In the present study, data collection of continuous speed development was not performed and for that reason association measures with the accelerometry scores developed throughout the course of the SAFT^{90} that could justify our hypothesis cannot be statistically addressed. We suggest that further research can complement the present findings by addressing this matter.

Our analysis showed that for PL there is a moderate positive association between all efforts, meaning that the participants modify their performance in a similar proportion, which was expected considering that PL is a representation of the sum of accelerations and decelerations. However, when expressions of intensity were considered the variation was not similarly proportional between the stride and sprint tasks. This observation is likely related to the fact that three participants could not increase their speed between these efforts, as seen in Figure 4 from the three lines that do not increase between stride and sprint. As this is contrary to the remaining participants, this appears to have created the variation of ranking, and therefore the use of PL.min^{-1} may allow an alternative differentiation among participants that should be addressed in further research in terms of meaningfulness for injury risk or load monitoring. So altogether, we would conclude that with increasing speed the increase in PL and PL.min^{-1} is similar between participants but further research would need to confirm this.

Our study comes with limitations. The match simulation protocol adopted excluded actions involving ball contact. Actions involving the ball typically only represent a small proportion of actions done during training or games (Carling, 2010; Rampini, Impellizzeri, Castagnac, Coutts, & Wisloff, 2009), and will likely only have a small impact on PL. Also, the SAFT^{90} match simulation was performed on a surface not specific for football practice, and this may have had a different impact on the acceleration and deceleration behaviour of the participants compared to turf surfaces in football practice. Similarly, differences in ground stiffness and damping behaviour exist between natural and artificial turf (Zanetti, Bignardi, Francheschini, & Audenino, 2013). It is still to be seen how surface characteristics affect trunk accelerometry, something that is hard to predict as the players will likely alter their biomechanical running strategy to compensate for higher impact forces on harder surfaces. However, although the stiffness of the laboratorial floor surface may have affected the PL accumulated score, we believe that the proportion between the scores would be kept the same.

Conclusion

The use of PL for monitoring accelerations and decelerations in football multidirectional actions using data from the accelerometer inbuilt in trunk mounted GPS devices presents moderate to high reliability across tasks performed at different speeds, ranging from moderate intensity efforts such as jogging to maximal efforts such as sprinting, and therefore can be used to monitor these types of efforts in football. There is significant variation between participants which was not associated with the participants´ anthropometrics and most likely relies on the individual’s locomotive skills. Whilst PL measures the cumulative load, PL.min^{-1} measures the intensity of a task. Different football related running actions showed different PL.min^{-1} values, which to a certain extent was related to the running velocity that needed to be achieved in a small space.

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Figures

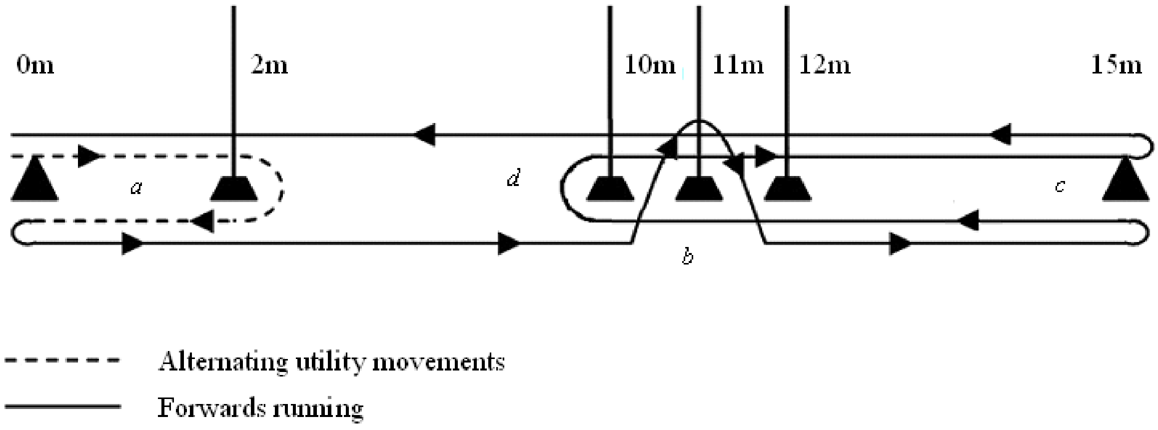
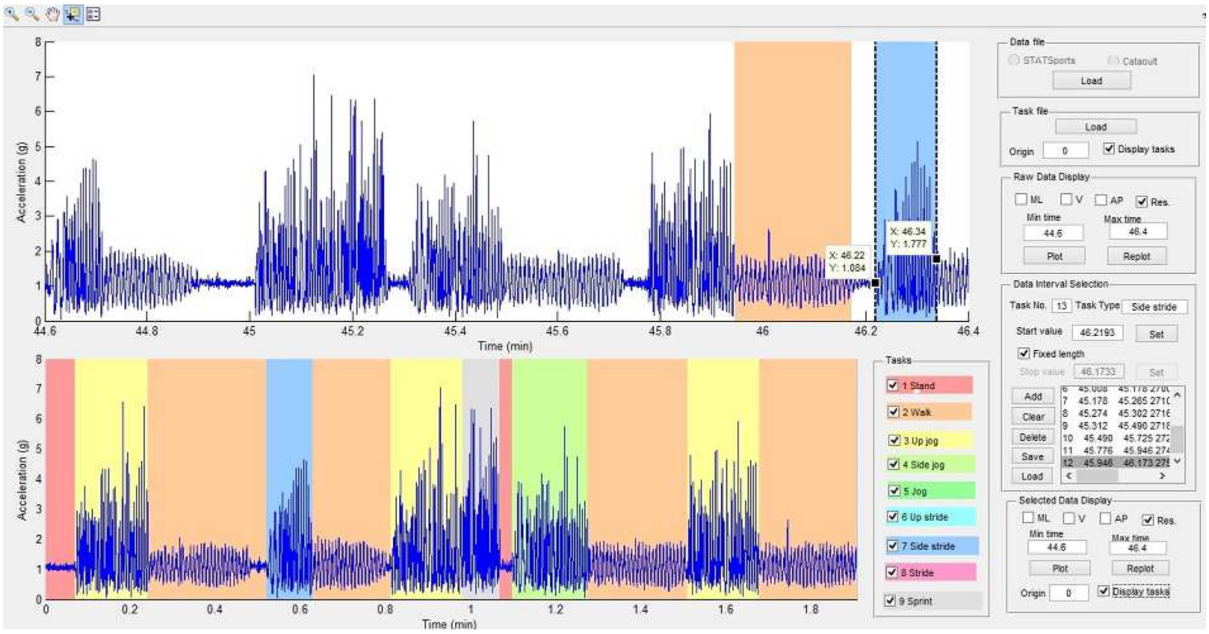


Figure 1. Diagram of the mSAFT^{90} laboratorial field course. Reprinted by permission from Taylor & Francis Publishers (Azidin et al., 2015), copyright 2015. Up and Side Jog: back and forward or sideways jogging between cones (a), straight line jogging followed by zig-zag between poles (b), 180º turn (c) and short stop at a designated mark (d), followed by jog and a second 180º turn (c) and final jog up to the starting point (a). Side cut: stride back and forward or sideways between cones (a), straight line stride and side cut at a designated mark signed with a force platform in the floor. Stride: straight line stride after side cut task to initial position (a) with 5 seconds stoppage time in between. Sprint: maximal sprint from the designated mark (d) to the starting position (a) including a 180º turn (c) following an initial up and side jog up to (d).



Task file: Origin 0 ☑ Display tasks

Raw Data Display: ☐ ML ☐ V ☐ AP ☑ Res. Min time 44.6 Max time 46.4

Data Interval Selection: Task No. 13 Task Type Side stride

Start value 46.2193

☑ Fixed length

Stop value 46.1733

6 45.008 45.178 270
7 45.178 45.265 271
8 45.274 45.302 271
9 45.312 45.490 271
10 45.490 45.725 272
11 45.776 45.946 274
12 45.946 46.173 275

Selected Data Display: ☐ ML ☐ V ☐ AP ☑ Res. Min time 44.6 Max time 46.4

Origin 0 ☑ Display tasks

Tasks:
☑ 1 Stand
☑ 2 Walk
☑ 3 Up jog
☑ 4 Side jog
☑ 5 Jog
☑ 6 Up stride
☑ 7 Side stride
☑ 8 Stride
☑ 9 Sprint

Figure 2. Custom Matlab template.

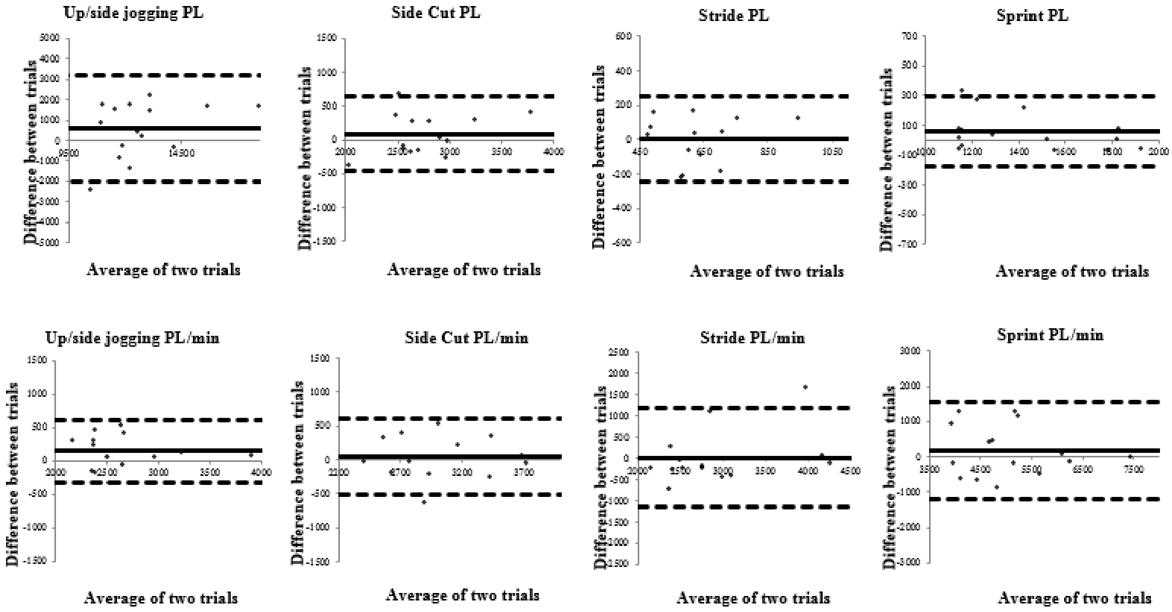


Figure 3. Bland-Altman plots for PL (upper row) and PL.min-1 (lower row) for up/side jogging tasks, side cut, stride and sprint (left to right), showing systematic bias (full horizontal line) and lower/upper limits of agreement (dashed lines).

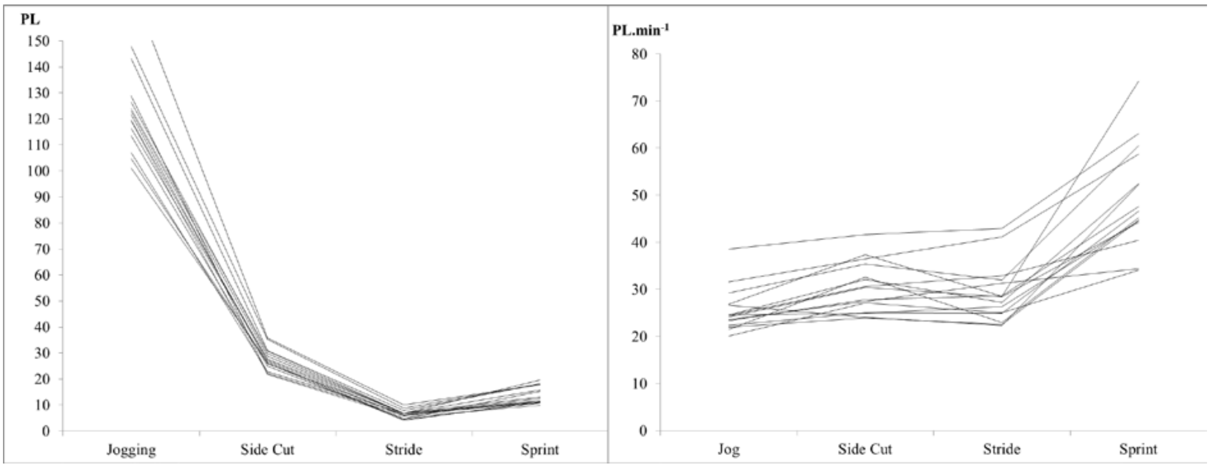


Figure 4. Within-participant variations of PL (left) and PL.min-1 (right) between tasks. Each line represents one participant.

Tables

Table 1. Activities analysed during the 15 minutes SAFT90 profile

Activity type	**Total number of activities**	**Speed (Km.h$^{-1)}$**
Total jogging	**29**	10.3
Up jog, zigzag and 180º turn[1]	17	
Side jog, zigzag and 180º turn[1]	12	
Total side cut	**8**	15.0
Up stride and side cut[2]	2	
Side stride and side cut[2]	6	
Total strides[3]	**2**	15.0
Total sprints[4]	**3**	≥ 20.4

Table 2. 15-30 minutes SAFT90 results and reliability analysis

	PL (Mean ± SD)					PL.min-^{1}(Mean ± SD)				
Task	Trial 1	Trial 2	t	p	r	Trial 1	Trial 2	t	p	r
Jogging	13037.8 ± 2309.7	12448.0 ± 1803.4	1.667	0.118	0.863	2699.2 ± 450.2	2558.6 ± 466.8	2.223	0.043	0.903
Side cut	2861.0 ± 507.9	2773.7 ± 422.9	1.173	0.260	0.892	3088.5 ± 538.8	3047.2 ± 542.8	0.535	0.601	0.921
Stride	655.2 ± 172.7	652.3 ± 159.5	0.090	0.929	0.831	2935.6 ± 844.2	2915.5 ± 618.7	0.127	0.901	0.806
Sprint	1442.2 ± 280.4	1385.4 ± 324.4	1.753	0.102	0.949	5134.5 ± 1005.8	4953.8 ± 1093.0	0.963	0.352	0.865

Table 3. Variation of LOA for PL and PL.min^{-1}

	Variation of LOA (relative to average difference between trials)	
	PL	PL.min^{-1}
Up/side Jogging	2595.5 (20.4%)	463.8 (17.6%)
Side cut	547.0 (19.4%)	566.2 (18.5%)
Stride	246.5 (37.7%)	1161.7 (39.7%)
Sprint	237.5 (16.8%)	1375.4 (27.3%)

Table 4. Trial 2 between subject and between task comparisons

.

	PL (Mean ± SD)					PL.min^{-1} (Mean ± SD)				
Task	Jogging	Side cut	Stride	Sprint	p	Jogging	Side cut	Stride	Sprint	p
Trial 2	12448.0 ± 1803.4	2773.7 ± 422.9	652.3 ± 159.5	1385.4 ± 324.4	0.000*	2558.6 ± 466.8	3047.2 ± 542.8	2915.5 ± 618.7	4953.8 ± 1093.0	0.000
CV	14.5%	15.2%	24.5%	23.4%		18.2%	17.8%	21.2%	22.1%	
Association- Height	-0.416	-0.317	-0.611**	-0.392		-0.411	-0.406	-0.482**	-0.302	
Association- Weight	-0.277	-0.239	-0.367	-0.338		-0.312	-0.283	-0.239	-0.340	
Association- BMI	0.033	-0.180	0.128	-0.065		-0.032	0.034	0.189	-0.190	

*Sphericity criterion not met, Greenhouse-Geisser correction used.

** Statistical significance ($p<0.05$)