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Effect of Isolated Vs in-Game Curvilinear Displacements in Multi-Location External Workload Profile. A Case Study in Semi-Professional Basketball Players

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Abstract

In team sports, linear and non-linear displacements are combined during the game. In this sense, the importance of curvilinear trajectories and their impact on body joints have not been addressed yet. Therefore, the present research aims to: (a) describe the multi-location external workload profile during curvilinear displacements in isolated and in-game conditions, (b) compare the effect of direction and displacement context, and (c) analyse the correlation between impacts and curvilinear performance. Thirteen semi-professional male basketball players were assessed in two tests: (a) isolated (2 directions x 5 repetitions x 6.75-m line) and (b) in-game (10-min 3vs3 small-sided game). To evaluate curvilinear performance and impacts suffered per joints, six WIMU PRO^{TM} inertial devices (scapulae, centre of mass, 2x knee, 2x ankle) were placed through a specific integral whole-body vest. Statistical analysis was composed by ANOVA with Bonferroni post-hoc, t-test for independent samples and Pearson correlation coefficient, analysing the effect of magnitude by Cohen's d and omega partial squared. The key findings indicate that straight displacements presented lower external workload than curvilinear displacements during in-game conditions (p<.01; ω_p^2= 0.47-to-0.50), but no differences were found between left and right directions (p>0.67; d<0.12). In addition, differences were found at lower limb locations in external workload in maximum sprinting during curvilinear displacements, with higher workload at left lower limb in right direction (knee: p<.01, d= -1.35; ankle: p<.01, d= -0.91), and at right lower limb in left direction (knee: p<.01, d= 1.23; ankle: p<.01, d= 0.91). Very high between-subjects variability has been shown in both tests. Besides, a nearly perfect relationship between external workload at different body locations (p<.01; r>0.918) and a high relationship between external workload and centripetal force were found (p<.01; r>0.518). In conclusion, curvilinear displacements should be trained specifically and, in both directions, due to the differences presented with straight displacements, considering the lower limb joints (knee and ankle). Due to the demands during in-game situations represent around 50% of maximum centripetal force and 20-to-40% of maximum external workload, a sprinting test with curvilinear displacements seems to be optimum to detect asymmetries for design training programs to reduce the injury risk in team sports players, specifically in basketball.

Keywords: accelerometry, inertial devices, joints, impacts, non-linear displacements.

Introduction

Basketball is a court-based team sport with intermittent physical demands produced by repeated transitions between offence and defence (Stojanović et al., 2018). Due to the basketball game dynamics, frequent activity changes are performed combining periods of high-intensity with low-intensity activity in all competitive levels and genres (Ferioli et al., 2020; Reina, García-Rubio, & Ibáñez, 2020). Recent studies focusing on elite and young male players found through principal component analysis that changes of speed (accelerations and decelerations), changes of direction (CoD), jumps, high-intensity and sprinting displacements are essential in basketball performance (Svilar, Castellano, Jukic, and Casamichana (2018); Pino-Ortega, Gómez-Carmona, Nakamura, & Rojas-Valverde, 2020). Thus, the analysis of actions in competition, both volume and intensity, is necessary to determine the specific physical athletes' profile and design training sessions and evaluation tests according to it (Fox, Stanton, & Scanlan, 2018; Mancha-Triguero, Garcia-Rubio, Calleja-Gonzalez, & Ibanez, 2019a)

One of these physical components is the change of direction. Change of direction is considered to be the specific event where the linear trajectory of displacement is modified, and it can occur during planned or non-planned conditions, where balance and body control have a fundamental role (Nimphius, Callaghan, Bezodis, &

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Lockie, 2018). During curvilinear displacements, the centrifugal and centripetal force is added to the vertical and horizontal forces that influence the linear displacements, being the centripetal force that is performed by the athlete and directed towards the centre of the curvature and the centrifugal force that counteracts centripetal force and takes out the athlete from the curvilinear trajectory (Resnick, Halliday, & Krane, 2002).

For monitoring basketball workload, different technologies have been developed in the last years; from video-analysis to electronic performance and tracking systems (EPTS) in outdoor and indoor conditions and microtechnologies (e.g., wearable microsensors and accelerometers) (Cummins, Orr, O'Connor, & West, 2013). Microtechnologies have become a valid and practical alternative due to their reliability, precision, and sensitivity with the detection of high-intensity actions without locomotion (jumps, collisions, etc.). (Fox, Scanlan, & Stanton, 2017; Gómez-Carmona, Bastida-Castillo, Ibáñez, & Pino-Ortega, 2020) For this reason, a combination of technologies has been incorporated in new devices to sum the advantages and indexes of these systems and to obtain new variables for performance monitoring as the centripetal force during curvilinear displacements (Granero-Gil et al., 2021).

Although the most common location to measure external workload in basketball is at scapulae as it is admitted as the best location for EPTS signal reception (Reina, García-Rubio, Feu, & Ibáñez, 2019); a recent study found that accelerometers only record the acceleration of the body segment that they are attached due to multi-joint complexity during sports movements (Nedergaard et al., 2017). In this sense, previous research found higher workload in lower limb in comparison to upper limb, especially in ankles (Gómez-Carmona, Bastida-Castillo, García-Rubio, Ibáñez, & Pino-Ortega, 2019; Gómez-Carmona, Bastida-Castillo, Moreno-Pérez, Ibáñez, & Pino-Ortega, 2021). Therefore, monitoring at different body locations simultaneously could be a solution to improve the accuracy of workload registering and it can provide useful information for performance enhancement, injury prevention and return to play in team sports performance. (Gómez-Carmona et al., 2020) Finally, the purposes of the present research were to: (a) describe the multi-location external workload profile during curvilinear displacements in isolated and in-game conditions, (b) compare the effect of direction and displacement context, and (c) analyse the correlation between impacts and curvilinear performance.

Methods

Design

The investigation presented a descriptive and comparative design to determine the external multi-location workload profile in curvilinear displacements during isolated and in-game conditions, specifically in basketball. In this study, no intervention has been performed so that only a non-invasive monitorization through inertial measurement units in different body locations can be realized in the court (Ato, López-García, & Benavente, 2013).

Participants

13 semi-professional male basketball players have participated voluntarily in the present study (age: 19.48±1.41 years; body mass: 87.63±7.98 kg.; height: 1.91±0.07 cm.; body mass index (BMI): 23.98±1.45 kg/m^2). All the players met the following inclusion and exclusion criteria: (a) absence of musculoskeletal injury or health problem that impedes their participation in the testing, and (b) have an experience of high-level monitoring by electronic performance tracking systems (EPTS) both in training and official games over than two months (Chambers, Gabbett, Cole, & Beard, 2015). Club managers, technical staff and players were previously informed about the investigation details and signed informed consent. The study was performed based on the ethical guidelines of the Declaration of Helsinki (2013) and approved by the Bioethics Committee of the University (registration number 232/2019).

Variables

Anthropometric characteristics. Height, weight, and BMI were assessed to characterise the participants in the study. PlayerLoad$_{RT}$ (PL$_{RT}$). This variable was utilized to measure the external workload of the different body locations was Player Load by RealTrack Systems company (PL$_{RT}$). This variable is an accelerometer-derived measurement of total body load in its 3 axes (vertical, anterior-posterior and medial-lateral) which have been used to evaluate the neuromuscular load in different athletes (Gomez-Carmona et al., 2020). It is represented in arbitrary units (a.u.) and is calculated from the following equation at a 100 Hz sampling frequency where: PL$_n$ is the player load calculated in the current instant; n is the current instant in time; n-1 is the previous instant in time; X$_n$, Y$_n$ and Z$_n$ are the values of Body Load for each axis of movement in the current instant in time; X$_{n-1}$, Y$_{n-1}$ and Z$_{n-1}$ are the values of Body Load for each axis of movement in the previous instant in time.

$$PL_n = \sqrt{\frac{(X_n - X_{n-1})^2 + (Y_n - Y_{n-1})^2 + (Z_n - Z_{n-1})^2}{100}}$$

$$Accumulated\ PL = \sum_{n=0}^{m} PL_n\ x\ \ 0{,}01$$

Centripetal force (Cent$_F$). The centripetal force is the force or force component acting on a moving object performed by the athlete which is directed towards the centre of the curvature (Resnick et al., 2002). It was obtained by multiplying mass, turning radius and angular velocity squared. Mass was obtained previously during each session and inserted into DIR CHANGES monitor of SPRO™ software. DIR CHANGES monitor obtained angular velocity through Euler values and turning radius through dividing linear velocity from UWB by angular velocity (Granero-Gil et al., 2021).

Equipment

Anthropometric characteristics. Height was registered through a rod stadiometer (SECA, Hamburg, Germany) and body composition through an 8-electrode segmental monitor MC-780MA model (TANITA, Tokyo, Japan).

External workload. PlayerLoad$_{RT}$ and Cent$_F$ were obtained through WIMU PRO™ inertial measurement units (RealTrack Systems, Almeria, Spain). These devices contain four 3D accelerometers (full-scale ranges: ±16g, ±16g, ±32g and ±400g), as well as other sensors (three 3D gyroscopes with 8000°/s full-scale output range, a 3D magnetometer, a 10-Hz global positioning system, a 20-Hz ultra-wideband). Previous studies have shown satisfactory reliability and accuracy results of inertial device sensors (accelerometers and gyroscopes) in static and dynamic conditions (Gómez-Carmona et al., 2019; Pino-Ortega, Bastida-Castillo, Hernández-Belmonte, & Gómez-Carmona, 2020). Gyroscope and accelerometer were set with a sampling frequency of 100 Hz, the minimum recommended to register external workload in sport (Gómez-Carmona et al., 2020).

To detect PL$_{RT}$ and Cent$_F$, the microelectromechanical sensors (accelerometer, gyroscope, and magnetometer) and indoor tracking sensor (ultrawide-band, UWB) have been utilized. The UWB tracking system was installed and calibrated following a recent study conducted by Pino-Ortega, Bastida-Castillo, Gómez-Carmona, and Rico-González (2020), where almost perfect validity and reliability was obtained. Before the evaluation and following the manufacturer recommendations related to microelectromechanical sensors, three actions were performed: (1) turn on the device on a flat zone, (2) maintain static during 30-seconds and, (3) without electromagnetic devices around it (Gómez-Carmona et al., 2019). In addition, this protocol was performed in the centre of the court to synchronize each device with the UWB tracking system.

Procedures

The players' assessment was realised in the habitual court of training. Before the data register, athletes were cited 30-minutes before the testing to locate the high-monitoring systems. The protocol was composed of four sessions. The first three sessions anthropometrical assessment (height, weight and human body composition), explanation of the study purposes and familiarization with the high monitoring were carried out. Then, the assessment of the isolated and in-game curvilinear displacement performance was performed in the fourth session through two tests previously designed and validated by an expert committee. The tests performed were as follows:

a) isolated curvilinear displacement: Athletes ran at maximum speed on 6.75-m line. Participants realized ten repetitions, where five repetitions were performed in each direction (left and right). When athletes finished each repetition, an active rest of 1 minute was realized. During the test, athletes must run into the 6.75-m line and the 1-m line courtesy. If the participants fall or run out of the track, a new repetition was performed (Fig. 1a) (Mancha-Triguero, García-Rubio, & Ibáñez, 2019b).
b) in-game conditions: 10-min of a 3vs3 small-sided game was played with 3vs3 official rules in a reduced court with dimensions of 10x15 (Fig. 1b) (Gómez-Carmona, Pino-Ortega, & Ibáñez, 2020).

20-minutes before the start of the testing, a specific warm-up was realized to achieve the best physical performance of the athletes where they worked different types of displacement and physical capacities. The distribution of the warm-up was composed of 10 minutes of moderate activity, 5 minutes of dynamic stretching and 3 minutes of light activity to prepare for the start of the testing. An active recovery of 5-minutes between test was carried out.

The high-monitorization was performed by six inertial devices located in six anatomical locations simultaneously: (i) back (inter-scapulae line), (ii) lumbar zone (L3-L5, centre of mass), (iii) knee (3-cm above the kneecap's crack) and (iv) ankle (3-cm above the lateral malleolus) (Gómez-Carmona et al., 2019). In knee and ankle, the devices were in the external side in both legs. The athlete wore 0.5 kg extra (70-90 gr per six devices) during the testing. The annexing of the six devices in the athlete's body was realized through a specific one-piece sport vest (150-200 gr) adapted anatomically with two parts: (a) upper body with two interior pockets to attach the back and lumbar devices, as well as an extensible band over the lumbar region to securely fix the device (see Figure 1c); and (b) lower body with four exterior pockets with elastic bands to fix the devices in knees and ankles (see Figure 1d). Finally, the data was downloaded, and the six inertial devices have been synchronized in the same timeline to be able to compare the register data during the same joint action.

Statistical analysis

After importing data to SPRO™ software, data of in-game conditions was divided into 4-second sections (n= 150 cases per subject) to be able to compare with isolated conditions (average: 4.02±0.23 seconds). Following this, a descriptive analysis (mean ± standard deviation, M ± SD) was performed. Moreover, an exploratory analysis to determine the distribution and the homogeneity of data was realized through the Kolmogorov-Smirnov test and

Levene test respectively, showing a parametric distribution. ANOVA was used to compare data between straight displacements and right and left changes of direction during in-game conditions with Bonferroni post-hoc, while t-test for independent samples have been utilized for comparison between left and right curvilinear displacements in isolated conditions. The effect sizes were obtained by omega partial square (ω_p^2) and Cohen's d (d). ω_p^2 is interpreted as follows: >0.01 *low*, >0.06 *moderate*, and >0.14 *high*; and d was interpreted as: d< 0.2 *trivial*, d=0.2-to-0.6 *low*, d=0.6-to-1.2 *moderate*, d=1.2-to-2.0 *high*, and d>2.0 *very high* (Hopkins, Marshall, Batterham, & Hanin, 2009).

Finally, a correlational analysis to identify relationships between PL_{RT} in each anatomical location with $Cent_F$ generated during isolated and in-game conditions was performed using the Pearson correlation coefficient, interpreted as follows: *insignificant* (r< 0.1), *low* (r= 0.1-to-0.3), *moderate* (r= 0.3-to-0.5), *high* (r= 0.5-to-0.7), *very high* (r= 0.7-to-0.9), *almost perfect* (r= 0.9-to-0.99) and perfect (r= 1.0) (Hopkins et al., 2009). The significance level is established at p<.05. Data analysis was performed using Statistical Package for the Social Science (SPSS Statistics, version 24, IBM Corporation, Armonk, NY, USA) and figures were designed by GraphPad Prism (Graphpad Ltd., versión 8, La Jolla, CA, USA).

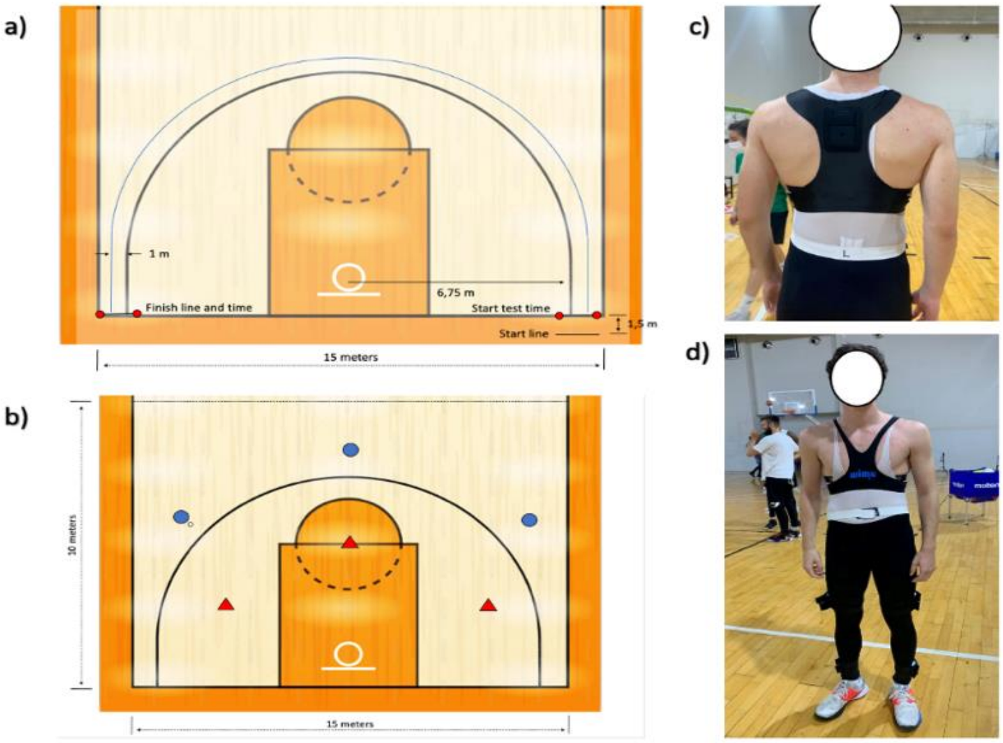

Figure 1. (a) 6.75-m line maximum sprinting test; (b) 3vs3 small-sided game; (c) location of inertial devices in the upper body; (d) location of inertial devices in the lower body.

RESULTS

Table 1 shows the descriptive and comparative analysis of external workload at each anatomical location and centripetal force generated during in-game conditions at the different directions of displacement. Lower demands in external workload are found between straight and curvilinear displacements with high effect size (p<.01; ω_p^2= 0.47-to-0.50; left = right > straight). Instead, no differences in external workload (p>.67; d<0.12) and centripetal force (p=.88; d=0.02) have found between directions in curvilinear displacements. Specifically, only two players show differences in external workload at lower limb locations with higher workload at left knee and left ankle in right displacements (number 8), and centre of mass, right knee and right ankle in left displacements (number 9). Besides, high between-subjects variability was found at all anatomical locations, all displacements and centripetal force generated during in-game conditions (p<.01; ω_p^2> 0.40).

The descriptive and comparative analysis between right and left curvilinear displacements on isolated conditions are found in Table 2. Higher values are found at left lower limb in right curvilinear displacements and at right lower limb in left curvilinear displacements with high effect size at knee (right knee: p<.01, d=1.23; left knee: p<.01, d= -1.35) and moderate effect size at ankle (right ankle: p<.01, d=0.91; left ankle: p<.01, d= -0.91). Instead, no differences are found at upper limb (scapulae: p=.37, d=0.26; centre of mass: p=.81, d= 0.02) and in centripetal force (p=.74, d=0.08). In individual analysis, seven participants show differences at scapulae (1,2,3,8,9,11,12), seven participants at centre of mass (3,4,7,8,9,10,11), ten participants at right knee (1,2,3,4,5,6,9,10,11,13), twelve participants at right knee (all except 8), ten participants at right ankle (1,2,3,4,5,6,10,11,12,13), and ten participants at left ankle (1,2,3,4,5,6,9,10,11,12).

Table 1

Descriptive and comparative analysis of PL_{RT} and $Cent_F$ during straight and curvilinear displacements in the small-sided game.

S	Straight displacements (M±SD)							Left curvilinear displacements								Right curvilinear displacements (M±SD)								Effect size and differences						
	n	Sc (M±SD)	Com (M±SD)	RK (M±SD)	LK (M±SD)	RA (M±SD)	LA (M±SD)	*n*	Sc (M±SD)	Com (M±SD)	RK (M±SD)	LK (M±SD)	RA (M±SD)	LA (M±SD)	$Cent_F$ (M±SD)	*n*	Sc (M±SD)	Com(M±SD)	RK(M±SD)	LK(M±SD)	RA(M±SD)	LA(M±SD)	$Cent_F$(M±SD)	Sc(ω_p^2)	Com(ω_p^2)	RK(ω_p^2)	LK(ω_p^2)	RA(ω_p^2)	LA(ω_p^2)	$Cent_F$(*d*)
1	68	.05±.03	.09±.06	.15±.09	.17±.12	.22±.14	.25±.15	37	.10±.06^{a}	.17±.10^{a}	.27±.15^{a}	.26±.15^{a}	.37±.19^{a}	.36±.21^{a}	238.36±120.80	45	.09±.06^{a}	.17±.10^{a}	.26±.15^{a}	.29±.17^{a}	.37±.21^{a}	.40±.20^{a}	253.38±247.63	0.28*	0.27*	0.28*	0.23*	0.27*	0.21*	0.07
2	53	.06±.03	.09±.04	.16±.06	.16±.07	.23±.08	.25±.10	50	.09±.03^{a}	.14±.06^{a}	.23±.09^{a}	.22±.08^{a}	.32±.11^{a}	.34±.13^{a}	244.60±126.87	47	.08±.03^{a}	.13±.05^{a}	.21±.08^{a}	.23±.08^{a}	.29±.10^{a}	.35±.13^{a}	247.63±104.52	0.19*	0.23*	0.22*	0.27*	0.21*	0.22*	0.02
3	64	.06±.03	.09±.05	.15±.07	.15±.07	.22±.12	.20±.10	42	.10±.05^{a}	.17±.08^{a}	.27±.12^{a}	.25±.13^{a}	.38±.17^{a}	.35±.19^{a}	286.84±163.87	44	.09±.04^{a}	.15±.07^{a}	.23±.09^{a}	.22±.09^{a}	.32±.13^{a}	.32±.14^{a}	279.39±127.71	0.27*	0.29*	0.32*	0.26*	0.29*	0.27*	-0.05
4	81	.05±.03	.09±.07	.10±.07	.11±.07	.15±.10	.17±.11	36	.10±.05^{a}	.19±.12^{a}	.22±.13^{a}	.22±.12^{a}	.28±.16^{a}	.33±.18^{a}	286.79±150.37	33	.10±.05^{a}	.19±.10^{a}	.20±.10^{a}	.22±.12^{a}	.25±.12^{a}	.31±.16^{a}	259.68±151.98	0.39*	0.36*	0.39*	0.37*	0.33*	0.33*	-0.18
5	60	.06±.04	.11±.06	.18±.10	.16±.09	.24±.14	.24±.14	50	.11±.03^{a}	.20±.07^{a}	.31±.10^{a}	.29±.10^{a}	.40±.14^{a}	.41±.15^{a}	217.25±99.04	40	.10±.04^{a}	.18±.08^{a}	.29±.12^{a}	.28±.12^{a}	.37±.17^{a}	.41±.17^{a}	241.43±94.96	0.43*	0.46*	0.36*	0.44*	0.35*	0.38*	0.24
6	59	.06±.03	.12±.07	.17±.10	.17±.08	.23±.13	.22±.11	44	.10±.05^{a}	.19±.10^{a}	.27±.13^{a}	.27±.14^{a}	.36±.16^{a}	.36±.17^{a}	275.82±124.47	47	.10±.05^{a}	.19±.08^{a}	.25±.11^{a}	.27±.12^{a}	.33±.13^{a}	.36±.16^{a}	270.34±136.01	0.28*	0.29*	0.24*	0.29*	0.25*	0.32*	-0.04
7	62	.06±.03	.10±.04	.19±.08	.16±.06	.24±.09	.23±.10	45	.09±.04^{a}	.15±.07^{a}	.28±.14^{a}	.23±.09^{a}	.36±.18^{a}	.31±.13^{a}	205.92±165.11	43	.09±.04^{a}	.15±.07^{a}	.26±.11^{a}	.24±.10^{a}	.34±.15^{a}	.34±.14^{a}	238.75±130.89	0.30*	0.29*	0.24*	0.29*	0.23*	0.26*	0.22
8	68	.06±.03	.10±.06	.15±.09	.14±.08	.20±.13	.19±.11	30	.08±.04^{a}	.15±.07^{a}	.22±.10^{a}	.20±.08^{a}	.31±.13^{a}	.26±.11^{a}	224.64±87.76	52	.10±.04^{a}	.19±.07^{a}	.26±.09^{a}	.26±.10^{ab}	.36±.14^{a}	.36±.14^{ab}	209.76±89.83	0.36*	0.40*	0.39*	0.44*	0.40*	0.42*	-0.17
9	83	.05±.04	.09±.08	.15±.12	.14±.10	.20±.16	.20±.15	29	.10±.05^{ac}	.17±.07^{ac}	.29±.12^{ac}	.25±.11^{a}	.41±.18^{ac}	.36±.17^{a}	257.43±134.37	38	.08±.03^{a}	.13±.05^{a}	.22±.08^{a}	.21±.10^{a}	.31±.13^{a}	.33±.16^{a}	208.62±170.14	0.40*	0.35*	0.39*	0.34*	0.39*	0.36*	-0.31*
10	76	.04±.03	.07±.04	.14±.09	.12±.06	.21±.13	.17±.09	36	.09±.04^{a}	.14±.06^{a}	.26±.11^{a}	.25±.11^{a}	.38±.17^{a}	.36±.16^{a}	266.99±168.96	38	.08±.04^{a}	.13±.07^{a}	.25±.12^{a}	.24±.12^{a}	.35±.16^{a}	.32±.15^{a}	292.43±127.84	0.47*	0.44*	0.39*	0.51*	0.37*	0.45*	0.17
11	73	.05±.04	.08±.06	.14±.08	.14±.09	.21±.13	.21±.14	37	.09±.05^{a}	.16±.09^{a}	.25±.13^{a}	.22±.10^{a}	.35±.16^{a}	.32±.14^{a}	306.84±154.92	40	.11±.05^{a}	.19±.10^{a}	.28±.15^{a}	.26±.13^{a}	.40±.18^{a}	.40±.19^{a}	320.38±181.18	0.40*	0.38*	0.36*	0.36*	0.34*	0.34*	0.08
12	103	.04±.02	.08±.04	.12±.06	.11±.05	.17±.09	.15±.08	21	.07±.04^{a}	.14±.07^{a}	.21±.11^{a}	.20±.10^{a}	.29±.14^{a}	.25±.12^{a}	198.13±77.16	26	.08±.04^{a}	.16±.09^{a}	.22±.10^{a}	.25±.14^{a}	.30±.15^{a}	.34±.19^{a}	221.45±78.51	0.31*	0.38*	0.41*	0.39*	0.31*	0.38*	0.26
13	81	.04±.03	.09±.06	.11±.06	.12±.07	.18±.10	.19±.11	33	.08±.03^{a}	.19±.09^{a}	.22±.09^{a}	.23±.10^{a}	.33±.15^{a}	.36±.18^{a}	234.02±97.75	36	.09±.03^{a}	.21±.09^{a}	.22±.09^{a}	.24±.11^{a}	.34±.16^{a}	.36±.16^{a}	261.13±121.40	0.51*	0.52*	0.53*	0.49*	0.49*	0.43*	0.23
T	931	.05±.03	.09±.06	.14±.09	.14±.08	.20±.12	.20±.12	490	.09±.05^{a}	.17±.08^{a}	.26±.12^{a}	.24±.11^{a}	.35±.16^{a}	.34±.16^{a}	251.67±128.49	529	.09±.04^{a}	.17±.08^{a}	.24±.11^{a}	.25±.12^{a}	.34±.15^{a}	.35±.16^{a}	254.16±125.20	0.49*	0.48*	0.49*	0.50*	0.47*	0.48*	0.02

Note. S: Subject; T: Total; Sc: Scapulae PL_{RT}; Com: Centre of mass PL_{RT}; RK: Right knee PL_{RT}; LK: Left knee PL_{RT}; RA: Right ankle PL_{RT}; LA: Left ankle PL_{RT}; M: Mean; SD: Standard deviation; $Cent_F$: Centripetal force. *Statistical differences between type of displacements ($p<0.01$); ^{a}Statistical differences with straight displacements ($p<0.05$); ^{b}Statistical differences with left curvilinear displacements ($p<0.05$); ^{c}Statistical differences with right curvilinear displacements ($p<0.05$).

Table 2

Descriptive and comparative analysis of PL_{RT} and $Cent_F$ during curvilinear displacements in 6.75-m line test.

S	Left curvilinear displacements (M±SD)							Right curvilinear displacements (M±SD)							Differences and effect size						
	Sc	Com	RK	LK	RA	LA	$Cent_F$	Sc	Com	RK	LK	RA	LA	$Cent_F$	Sc(*d*)	Com(*d*)	RK(*d*)	LK(*d*)	RA(*d*)	LA(*d*)	$Cent_F$(*d*)
1	.39±.01	.51±.01	1.25±.01	.84±.15	1.59±.13	1.42±.04	524.36±19.57	.36±.01	.52±.01	.98±.07	1.07±.01	1.42±.09	1.33±.01	547.20±14.91	3.00**	-1.00	5.40**	-14.55**	1.52*	3.09*	-1.31
2	.43±.04	.55±.01	1.32±.04	1.01±.08	1.49±.02	1.23±.08	431.38±14.44	.40±.01	.54±.02	1.05±.01	1.44±.04	1.33±.08	1.75±.08	416.53±29.30	1.03	0.63	9.26**	-14.75**	2.74*	-6.50**	0.64
3	.32±.01	.49±.03	1.04±.04	.83±.13	1.31±.06	1.13±.03	510.89±7.66	.39±.02	.52±.01	.87±.02	1.13±.02	1.17±.01	1.34±.01	512.63±19.24	-4.42**	-1.34	5.38**	-15.00**	3.26*	-9.39**	-0.11
4	.47±.01	.91±.02	1.29±.02	1.13±.12	1.46±.08	1.43±.13	430.88±18.73	.45±.01	.85±.01	1.17±.04	1.42±.08	1.21±.03	1.83±.11	428.39±10.32	2.00*	3.80*	3.80**	-4.80**	4.14**	-3.32*	0.17
5	.40±.02	.83±.01	1.38±.06	1.16±.10	1.76±.13	1.58±.11	431.51±11.24	.40±.02	.83±.06	1.20±.03	1.45±.01	1.44±.02	1.92±.18	433.77±11.32	0.00	0.00	3.50*	-6.74**	3.44*	-2.28*	-0.20
6	.42±.04	.90±.10	1.34±.04	1.02±.14	1.69±.06	1.28±.04	505.14±40.83	.40±.01	.86±.01	1.04±.04	1.22±.02	1.29±.06	1.67±.01	531.39±3.90	0.68	0.56	7.50**	-3.88**	6.67**	-13.40**	-0.91
7	.58±.01	.70±.06	1.16±.08	1.02±.09	1.70±.07	1.28±.07	464.26±34.19	.59±.01	.76±.01	1.13±.07	.94±.01	1.71±.46	1.33±.15	456.39±18.53	-1.00	-1.40	0.40	2.74*	-0.03	-0.43	0.28
8	.40±.01	.72±.01	1.13±.03	1.04±.08	1.23±.04	1.17±.06	389.57±22.83	.36±.01	.82±.06	1.10±.06	1.19±.15	1.22±.14	1.29±.16	368.55±15.01	4.00**	-2.33*	0.63	-1.28	0.09	-0.99	1.24
9	.24±.01	.40±.03	.89±.07	.66±.11	.95±.02	.99±.13	482.84±28.38	.28±.01	.52±.02	.75±.01	.97±.06	.95±.07	1.31±.04	445.96±4.21	-4.00**	4.71**	2.80*	-6.08**	0.00	-3.32*	1.26
10	.40±.01	.66±.01	1.16±.06	.92±.11	1.69±.06	1.22±.10	484.59±14.46	.38±.01	.60±.02	.98±.01	1.23±.04	1.28±.03	1.37±.06	509.33±5.20	2.00*	3.80**	4.19**	-7.75**	8.64**	-1.82*	-2.27*
11	.50±.01	.72±.01	1.08±.01	.88±.10	1.48±.03	1.36±.01	520.38±5.23	.42±.01	.69±.02	.96±.04	.84±.02	1.29±.03	1.21±.07	491.52±1.20	8.00**	1.90*	4.12**	2.00*	6.33**	3.00*	7.60**
12	.43±.02	.72±.01	.96±.01	1.01±.10	1.61±.01	1.21±.04	425.93±10.31	.36±.01	.73±.03	.97±.04	1.23±.08	1.41±.05	1.53±.06	431.01±5.25	4.43**	-0.45	-0.34	-3.86**	5.54**	-6.28**	-0.62
13	.45±.02	.84±.02	1.36±.04	.91±.10	1.59±.12	1.44±.24	451.95±4.27	.44±.01	.82±.01	.88±.01	1.29±.08	1.17±.04	1.39±.01	443.50±2.08	0.63	1.27	16.46**	-6.52**	4.70**	0.29	2.51*
T	.42±.08	.69±.08	1.18±.16	.96±.13	1.50±.23	1.29±.17	465.67±44.63	.40±.07	.69±.14	1.00±.13	1.18±.19	1.30±.21	1.48±.24	462.01±52.92	0.26	0.02	1.23**	-1.35**	0.91**	-0.91**	0.08

Note. S: Subject; T: Total; Sc: Scapulae PL_{RT}; Com: Centre of mass PL_{RT}; RK: Right knee PL_{RT}; LK: Left knee PL_{RT}; RA: Right ankle PL_{RT}; LA: Left ankle PL_{RT}; M: Mean; SD: Standard deviation; $Cent_F$: Centripetal force. *Statistical differences between right and left curvilinear displacements ($p<0.05$); **Statistical differences between right and left curvilinear displacements ($p<0.01$).

Finally, Table 3 shows the correlational analysis between external workload and centripetal force performed during both tests in curvilinear displacements. A nearly perfect correlation is found between all anatomical locations in the external workload ($p<.01$; $r>$ .918). Besides, a high correlation is shown between external workload and centripetal force in all anatomical locations ($p<.01$; $r>$ .518).

Table 3

Correlational analysis between external workload at anatomical locations and centripetal force performed during curvilinear displacements

	Com	RK	LK	RA	LA	Cent$_F$
Sc	.958**	.958**	.940**	.953**	.936**	.534**
Com		.947**	.947**	.932**	.939**	.523**
RK			.934**	.978**	.935**	.521**
LK				.918**	.977**	.518**
RA					.924**	.530**
LA						.532**

Note. Sc: Scapulae PL$_{RT}$; Com: Centre of mass PL$_{RT}$; RK: Right knee PL$_{RT}$; LK: Left knee PL$_{RT}$; RA: Right ankle PL$_{RT}$; LA: Left ankle PL$_{RT}$; M: Mean; SD: Standard deviation; Cent$_F$: Centripetal force. **Significative correlations (p<.01).

Discussion

Currently, the studies that assess basketball physical performance have centred in the effect of contextual variables in technical-tactical actions, lineal displacements, jumps and collisions (Ferioli et al., 2020; Reina et al., 2020) Instead, although CoD actions as one of the most important skills in basketball, these displacements have received less attention and only one previous research analyses their performance during basketball (Svilar et al., 2018). For this reason, this study analyses during curvilinear displacements, the centripetal force and the multi-location external workload in isolated and in-game conditions. The main results of the present study demonstrate greater demands in curvilinear displacements in comparison with straight displacements, as well as lower demands on in-game conditions with respect to isolated tests with differences in external workload between lower-body joints.

Firstly, straight displacements represents lower demands than curvilinear displacements, both at right and left directions. When an athlete performs a change of direction, centripetal and centrifugal forces are added to horizontal and vertical forces that are involved in straight displacements (Resnick et al., 2002). These forces provoke a modification on the gait pattern of the athlete, and as consequence, the external workload suffered by the lower-body joints (Sankey, Robinson, & Vanrenterghem, 2020). For this reason, when a curvilinear displacement is performed, the musculoskeletal structures support greater external workload both in the lower and upper limb in comparison with straight displacements (Marshall et al., 2014). Therefore, strength and conditioning coaches should train specifically the displacements with curvilinear trajectories, being the intensity and duration equal or superior to competition with the aim to achieve the best competitive performance and the adaptation to these demands.

Subsequently, when the external workload demands are compared between isolated and in-game conditions, the results show that in-game demands represent around 50% of maximum centripetal force and between 20-to-40% of maximum external workload in the different anatomical locations, finding the highest differences in lower limb locations (knee and ankle). For this reason, while in straight displacements the external workload is distributed equally in lower-body joints, during curvilinear displacements at maximum intensity this distribution is not equal due to the fact that each leg has a specific role during the displacement. The inside leg needs to be the pivot point and help the impulse while the outside leg has to provide enough force to maintain the athlete into the curvature and has the determinant role of impulse (Courtine & Schieppati, 2003).

In addition, although a tendency is found in all players during maximum curvilinear efforts (inside leg lower external workload than outside leg), each player obtains a specific external workload and centripetal force profile during the test. This aspect is fundamental because each player has an individual profile of anthropometrical characteristics, musculoskeletal development and playing role in the court (Mujika, Halson, Burke, Balagué, & Farrow, 2018). Therefore, the straight and curvilinear displacements should train specifically, and each player should be trained individually to detect his/her strengths and weakness and preventive and/or return-to-play programs/training should be designed in a way as to adapt to each one.

Respect to correlation analysis, significant relationships are found between anatomical locations, so higher centripetal force supposes greater impacts at all anatomical locations. This aspect is important because higher centripetal force can produce higher body mass, velocity of displacements and turning radio (Dos'Santos, Thomas, Comfort, & Jones, 2018). These three parameters are fundamental to designing specific curvilinear training tasks for the development of skills/abilities of non-linear displacements (Nimphius et al., 2018). Besides, these tasks should be designed with caution because, as mention earlier, curvilinear displacements represents higher demands in external workload at all body locations, especially in lower body joints where most of the injuries are suffered in male and female basketball players (Reina et al., 2020; Zuckerman et al., 2018).

Finally, the present study is the first approach to external workload analysis in different body locations simultaneously during curvilinear displacements, and specifically in basketball through tests extracted of a field test battery previously validated through expert committee (Gómez-Carmona et al., 2020). The assessment of skills and abilities of basketball players out of competition context in isolated tests could provide a new point of view about the maximum demands of displacements, and complement the data obtained in the competition (Mancha-Triguero et al., 2019a). These values have special relevance as a reference point for each player to evaluate their progress in terms of physical capacities and skills/abilities through the season (Rojas-Valverde, Gómez-Carmona, Gutiérrez-Vargas, & Pino-Ortega, 2019).

While the results of this study provide information regarding the multi-location external workload and the centripetal force generated on in-game and isolated conditions in basketball, made possible by the use of an advanced tracking system, some limitations to the study must be acknowledged. In the present study, one team has been analysed in terms of anthropometrical characteristics, musculoskeletal development and tactics specific. For these reasons, the results of the present study should be taken into consideration with caution and generalizations should not be made. In addition, data collection is performed without modifying the individual gait pattern of the athletes, so that an ecological treatment for the study can be achieved. Future research may analyse through the protocol of multi-location external workload assessment provided in this study for different basketball common displacements (e.g., jumps, accelerations, decelerations, etc.) and complement the lateral differences with the assessment of musculoskeletal structures' absorption of impacts in team sports, and specifically in basketball.

Conclusions

The first results that analyse the external workload demands in different body locations simultaneously found higher demands in curvilinear displacements than straight displacements during in-game conditions, but no differences are found between the left and right direction. At maximum curvilinear sprinting, lower limb obtains different external workload profile in relation to the direction of displacement while upper limb obtains similar demands. Right ankle-knee obtained higher impacts in left curvilinear displacements and left ankle-knee in right curvilinear displacements. During in game and isolated conditions, an individual profile is found in each athlete both in external workload and centripetal force generated. Finally, higher centripetal force is related with higher external workload at all body locations.

Practical Applications

Movement demands in athletes should be regularly monitored by conditioning coaches and analysed individually per players. The specific considerations highlighted in this study provide initial guidelines for the use of multi-location external workload analysis during curvilinear displacements to detect asymmetries. As in-game situations are not sufficient to achieve the maximum curvilinear performance and the maximum external workload in each joint, isolated tests are presented as an alternative to analyse the external workload profile of players and detect weakness during displacements with non-linear trajectories. In addition, the analysis of the distribution of curvilinear displacements (ratio right-left change of direction) seems to be necessary with the aim of reducing the asymmetries in the number of changes of direction performed. This information could be useful for designing specific strength and conditioning programs to improve sports performance and reduce injury risk, where this isolated test could be used as a training task.

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