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Kinematics differences between a one-handed and a two-handed tennis backhand using gyroscopes. An exploratory study

Diferencias cinemáticas entre el revés a una y dos manos de tenis usando giróscopos. Un estudio exploratorio

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Abstract

The main objective of this article is to compare angular kinematics and intersegmental coordination of the upper limbs between one-handed and two handed backhands in a sample of 20 male competition players by using gyroscopes and compare ball speeds and accuracy obtained in both types of backhands. The angular kinematics, intersegmental coordination, ball speed and accuracy were compared during a specific stroke performance test using four inertial sensors (trunk, head, arm and forearm). We hypothesize that there will be significant differences in terms of ω_{peak} and intersegmental coordination in some of the segments measured between DH and SH by using gyroscopes, but the opposite will happen in the variables speed ball and accuracy. There are no significant differences between one-handed backhand and two-handed backhand in terms of speed and accuracy. Higher peaks angular speeds were found in the trunk and arm over the x axis in two-handed backhand which could indicate that this type of backhand generates greater trunk rotation and external rotation of the arm and forearm compared to one-handed backhand. The peak angular speeds were greater in the arm and forearm on the z axis in the case of one-handed backhand which is related to a greater extension of the forearm accompanied by a higher termination in the technical gesture. In conclusion, the proposed model of biomechanical analysis through the use of gyroscopes is especially useful for kinematic analysis of tennis strokes during field-based experimentation and could easily be adapted to other sports. It is also a low-cost and portable alternative that includes all instrumentation and data processing.

Keywords: *Wearable; inertial sensors; angular speed; upper body; racket sports.*

Resumen

El objetivo principal del presente estudio es comparar la cinemática angular y la coordinación intersegmentaria del tren superior entre el revés a una y dos manos de tenis en una muestra de 20 jugadores de nivel competición mediante el uso de giróscopos, y comparar las velocidades de pelota y la precisión obtenidas en ambos tipos de revés. La cinemática angular, la coordinación intersegmentaria, la velocidad de pelota y la precisión se obtuvieron de cada jugador mediante una prueba de golpeo realizada con cuatro sensores inerciales colocados (tronco, cabeza, brazo y antebrazo). Se sostiene la hipótesis de que se encontraran diferencias significativas en

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términos de ω_{pico} y coordinación intersegmentaria en alguno de los segmentos intervinientes en el revés a una y dos manos, pero sucederá lo contrario en las variables velocidad de pelota y precisión. Tras el análisis de los resultados, no se encontraron diferencias significativas entre el revés a una y dos manos en velocidad de pelota y precisión. Sin embargo, se encontraron velocidades angulares pico significativamente más altas en el tronco y brazo sobre el eje x en el revés a dos manos, lo que podría indicar que este tipo de revés genera una rotación de tronco y una rotación externa de brazo y antebrazo mayores que las del revés a una mano. Las velocidades angulares pico fueron significativamente mayores en el brazo y antebrazo sobre el eje z en el caso del revés a una mano, lo cual está relacionado con una mayor extensión del antebrazo acompañada de una terminación más alta del gesto técnico. En conclusión, el modelo propuesto de análisis biomecánico a través del uso de giróscopos es especialmente útil para el análisis cinemático de los golpes de tenis en estudios de campo y podría adaptarse fácilmente a otros deportes, suponiendo una alternativa portable y de bajo coste que además incluye toda la instrumentación y procesamiento de los datos.

Palabras clave: *Vestible; sensores inerciales; velocidad angular; tren superior; deportes de raqueta.*

INTRODUCTION

Physical fitness, motivation and tactical dexterity are important aspects to get a good performance in tennis, but the mechanical efficiency of the players´ strokes often determines the level of success both recreationally and competitively (Roetert et al, 1992). Although the forehand, compared to the backhand, allows for generating more speed which has an effect on the ball and it's accuracy after impact, this is also a basic groundstroke and is becoming increasingly important in modern tennis (Delgado-García et al., 2019; Fernandez-Fernandez et al., 2010; Reid, 2001). A player´s decision to use two-handed backhand (DH) or one-handed backhand (SH) is a key point in the tennis learning process, since the player will be able to obtain a major or minor biomechanical efficiency in this stroke depending on his decision (Genevois et al., 2015). For example, DH is the type of backhand that most of the baseline players usually choose, while the versatile players seem more likely to choose SH because it is easier for them making net approach strokes and backhands volleys (Genevois et al., 2015). Young tennis players prefer DH during their initiation phase since it requires less force than SH (Giangarra et al., 1993). Another factor that favors the selection of DH over SH in adult beginner players is that SH is more susceptible to tennis elbow (Giangarra et al., 1993; Roetert et al., 1995; Blackwell & Cole, 1994).

There is a need to carry out research that analyses the kinematics of the backhand since it is less studied than forehand or serve (Genevois et al., 2015; Bahamonde, 2005). The backhand is one of the two basic groundstrokes in tennis and the evolution of the backhand represents one of the biggest changes in tennis over the past decades (Genevois et al., 2015). The segments used for performing both backhands (DH and SH) are the same: hips, shoulder, upper arm and hand/racket rotation (Reid & Elliott, 2002). However, 3D photogrammetry research indicates biomechanical differences between DH and SH (Genevois et al., 2015; Giangarra et al., 1993; Akutagawa & Kojima, 2005). These studies show a sequential coordination between the different segments involved in performing the two backhands (Allen et al., 2016). It has been shown that intersegmentary coordination (IC) occurs from proximal to distal in terms of angular velocity and linear velocity (Marshall & Elliot, 2000) and that the moment of maximum trunk rotation acquires a fundamental character in the performance that we can achieve in this stroke (Genevois et al., 2015).

The biomechanical parameters of tennis strokes have been widely studied in laboratory conditions, but there is a shortage of studies that do it on the court (Allen et al., 2016). Only some biomechanical studies make of use inertial sensors in tennis (Cosac & Ionescu, 2015; Sharma et al, 2017), however after reviewing the literature, in most cases the devices are placed on the racket or forearm, and tennis performance is the result of sequenced whole body coordination (Allen et al., 2016). It will be vital also to analyze the trunk, arms and head to have a more complete monitoring of the kinematics of the stroke (Bertolotti et al., 2015).

Previous studies have shown that inertial measurement unit (IMU) gyroscopes are a valid alternative to 3D optical motion capture system for angular kinematics analysis in tennis (Delgado-García et al., 2021) since they allow capturing the rotational movements in the three axes of space; record the peak angular speeds (ω_{peak}) of the different segments and differentiating between different levels of play (Ahmadi et al., 2010). They also allow to discriminate the different phases of the strokes (Hansen et al., 2017; Büthe et al., 2016) and obtain the sequencing of the segments that are part of the kinematics of the stroke (Büthe et al., 2016).

The main objective of this article is to compare angular kinematics and intersegmental coordination of the upper limbs between two-handed and one-hand backhands in a sample of competition players by using gyroscopes. Additionally this study compares ball speeds and accuracy obtained in both types of backhand. We hypothesise that there will be significant differences in terms of ω_{peak} and intersegmental coordination in some of the segments measured between DH and SH by using gyroscopes, but the opposite will happen in the variables speed ball and accuracy.

METHOD

Sample

A sample of 20 male advanced players with a minimum of 15 years of experience (all of them were taking part in regional competitions) was used, 10 with DH and 10 with SH. The age range of the sample was 17 to 49 (29.55 ± 8.16) years. The anthropometric characteristics of the participants were obtained using the Inbody 230 bioimpedancemeter (Inbody Seoul, Korea). The average height of the sample was 177.33 cm ± 5.5 (means ± standard deviation), mass 79.3 kg ± 12.66, body mass index 25.9 ± 3.94, body fat mass 15.76 kg ± 9.34 and skeletal muscle mass 35.22 kg ± 4.48. Participants were instructed to have fasted in the previous two hours and not to have performed strenuous physical exercise in the 48 hours prior to the study. Sample exclusion criteria were musculoskeletal injury and the use of medications that could cause problems during the test. After receiving detailed information on the objectives and procedures of the study, each subject signed an informed consent form in order to participate, which complied with the ethical standards of the World Medical Association's Declaration of Helsinki (2013). It was made clear that the participants were free to leave the study if they saw fit. The study was approved by the Institutional Review Board.

Procedures

Specific stroke performance test

The test was performed on an indoor court with type A surface (International Tennis Federation [ITF], 2015). Each player used their own racket, which was previously checked to ensure that it was in good condition according to the criteria of the International Tennis Federation (International Tennis Federation [ITF], 2015). Since the tension of the racket strings affects the control and the power of the stroke (Brody & Roetert, 2004) it was measured with a tensiometer (Tourna stringmeter, EE.UU). The tensions of the rackets were in a range of 19 to 25 kilograms. Sixty new and well-pressurized tennis balls (Wilson Trainer) with weight and size characteristics were used within the standards allowed by the ITF (2015). The tennis ball machine (Lobster Gram Slam 4, Lobster Sport Inc. North Hollywood, CA. EE.UU) it was calibrated before the start of each test following the manufacturer's instructions. Before starting the test, participants performed a standardized 8-min warm-up divided into general warm-up (mobility exercises) and specific that it consisted of a 5-min rally with a high-level player (it was the same for all participants). The subjects were given a heart rate monitor with the aim of controlling heart rate and thus preventing fatigue from being a contaminating factor during the development of the protocol. The next stroke series was not started until the subject reached a difference maximum of 10 bpm regarding the pulsations measured just after warm-up (Lyons et al., 2013).

After the warm-up, the protocol was explained to the subjects. The stroke protocol is based on previous study of Lyons et al. (2013). A total of 600 backhands were recorded (300 DH and 300 SH). To ensure that the time between strokes was constant in all subjects and in all series the resultant angular speed (R_ω) of the forearm sensor was used, taking the moment of appearance of the peaks (each peak was considered an impact), following a similar process from a previous study to detect falls (Bourke & Lyons, 2008). The total average time between strokes was 3.42 ± 0.025 seconds. The test consisted of three stroke series (alternating forehand and backhand) with 20 strokes each. The participants always had to hit parallel trying to send the ball to the different objectives of the opposite court (figure 1). The players were asked to "achieve the objectives with the greatest possible speed", similar indication to that made in previous studies of stroke accuracy (Landlinger et al., 2010; Van den Tillaar & Ettema, 2006). The Stalker Pro II speed radar (Stalker Radar, Plano, Texas) was placed in the center of the track and was oriented parallel to the lateral lines with the intention of minimizing the error due to the angle of the trajectory of the ball (Kelley et al., 2010). The ball bounce was recorded at 60 Hz with a rear and aerial viewpoint using the Panasonic HC-V160EC-K camera (Panasonic, Japan) with the aim of obtaining the accuracy achieved by each player. The accuracy of each shot was evaluated according to the area of the court where the ball had bounced (Figure 1). The balls that bounced off these targets were scored with zero. The total accuracy was calculated as the percentage of points obtained in relation to the total points possible.

Analysis of the gyroscope signal

A peak analysis of the gyroscope signal (Nexgen Ergonomic, Montreal, Canada) was performed in order to find both the magnitude and the timing of maximum rotation (rad s^{-1}) of different segments during each stroke. Five sensors (Nexgen Ergonomic, Montreal, Canada) were placed on the trunk, head, arm, and dominant forearm. This sensor location follows the guidelines of previous works (Ahmadi et al., 2010; Grimpampi et al., 2016; Ahmadi et al., 2009). The locations and axes of each sensor is shown in Figure 2. They were used at a sampling frequency of 128 Hz and record synchronously between each other. According to the manufacturers x and y axis gyroscopes has a range of ± 2000 deg s^{-1} and a typical noise density of 0.81 mrad/s/ $\sqrt{hz}$ and the z axis has a range of 1500 deg s^{-1} and a typical noise density of 2.2 mrad/s/ $\sqrt{hz}$.

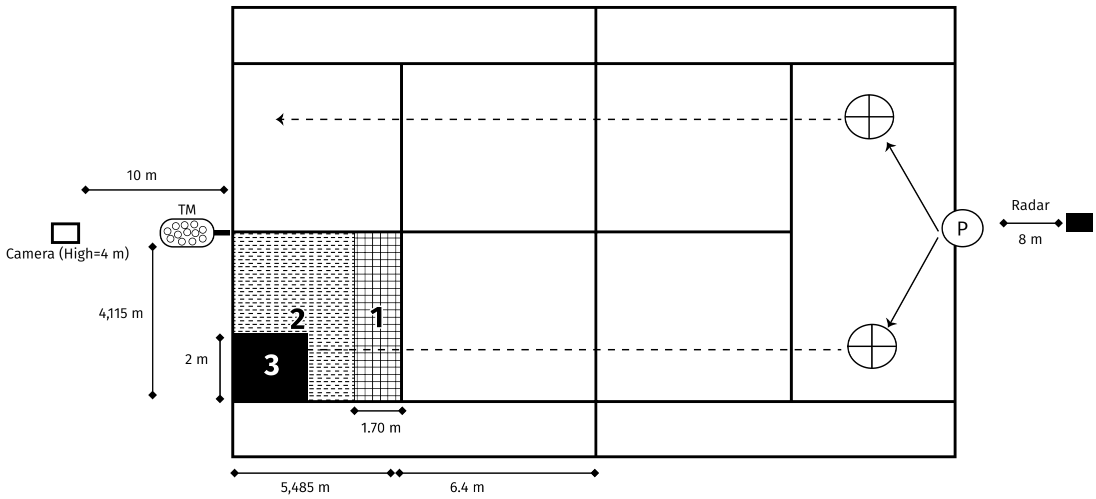

Figure 1. Stroke test with the dimensions and scores of the targets. The targets for the bottom shots are represented by the values 1, 2 and 3. The numbering of each zone corresponds to the score awarded to the participant. TM: Tennis ball machine.

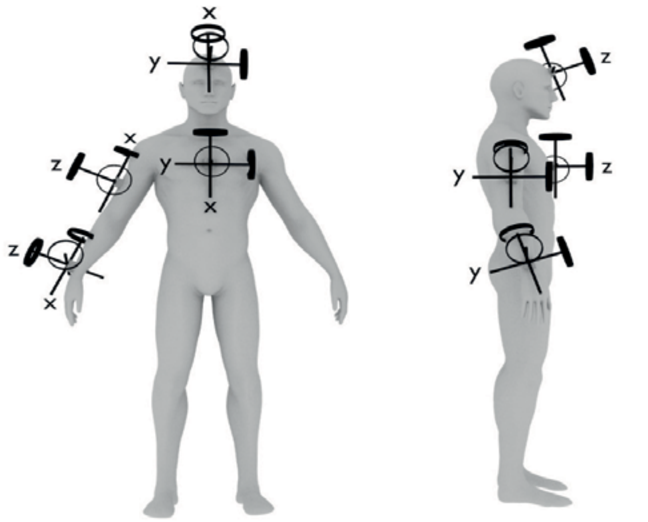

Figure 2. Positioning of the sensors and rotation axes. The circles represent the plane of rotation. The rotations on the x axis correspond to the turns on the longitudinal axis of the segment.

To verify the validity of the inertial sensors, an internal validation study was carried out with five subjects of different levels. The gyroscope signal was compared with a 3D photogrammetric analysis system (OptiTrack, Natural Point Corvallis, USA) and analyzed with Visual 3D (c-Motion, Inc., Rockville, MD, USA). The gyroscopes were placed in the same locations that in the stroke test described previously and each subject executed 5 series (2 series of forehands, 2 series of backhands and 1 series of serves) of 20 strokes each series hitting a ball fixed in an elastic bar (laboratory conditions). The signals of angular velocity in each of its axis (x, y and z) acquired with both systems (sensors gyroscopes and markers-based gyroscopes) was compared. For this, 300 correlations were made in which the average r was 0.985 ± 0.018 in forehand and backhand situations with and without the ball.

Angular Kinematic

The original unfiltered gyroscope signal was used so as to not modify the height of ω_{peak}. A semi-automatic peak search was carried out using the Origin 9 software (OriginLab Northampton, MA), with the function of the software "peak analysis". It was visually verified that the peaks were correctly selected with the TK Motion Studio software (APDM Inc, Portland, OR, USA), which allows us to capture the synchronized signal with a GoPro video camera (GoPro Inc., San Mateo, CA) set at 60 Hz, so that strange peaks can be identified and discarded. This analysis aimed to find both the magnitude and the timing of maximum rotation (rad/s) of the different segments during each stroke of the series. Taking into account the duration of a stroke and in order to avoid false positives, only those ω_{peak} that were found at ± 25 samples of the moment of appearance of the resulting peak of angular speed of the forearm ($R\omega_{peak}$ of the forearm). Other authors have also used the ω_{peak} to determine events (Bourke & Lyons, 2008).

Intersegmental coordination

A comparison of the Intersegmental coordination (IC) was made between ω_{peak} of the forearm (reference sensor) and ω_{peak} of the trunk, ω_{peak} of the head and ω_{peak} of the arm, for DH and SH. IC is related to the sequence of movements of the aforementioned segments. Other authors, like Grimpampi et al. (2016) have used the moment when the segment begins to rotate (angular velocity changes sign and increases or decreases significantly). However, in the present work it has been preferred to select the ω_{peak}, since in such explosive gestures as tennis strokes the moment of rotation start is more difficult to detect because the signal changes sign at several points on the x axis. In the case of trunk and arm, ω_{peak} were selected on the x axis (which corresponds to the longitudinal axis of these segments), where it is expected greatest angular speed will be found (due to the moment of inertia with a lower rotation radius).

In the case of the head, the resultant was selected ($R_{\omega peak}$ of the head), since it is more complex to determine the axis of rotation on which the maximum angular velocity occurs (the neck joint allows more degrees of freedom). The unit of IC is the number of samples. This unit can be transformed into time by dividing it by the sampling frequency of the sensors (128 Hz). Finally, IC was calculated by subtracting the moment of appearance of the ω_{peak} of the segment in question (trunk, head and arm) at $R_{\omega peak}$ of the forearm. $R_{\omega peak}$ of the forearm was considered the closest point to the impact of the ball. Bourke & Lyons (2008) also used R_{ω} but in a sensor placed on the trunk. In our study, a positive value in R_{ω} indicates that the peak appears after the moment of impact and vice versa.

STATISTIC ANALYSIS

Descriptive statistics are represented as mean and standard deviation. Tests of normal distribution and homogeneity, determined by the Kolmogorov Smirnov and Levene's test, respectively, were conducted on all data before analysis. The accuracy of each participant was presented as the percentage of points achieved with respect to the total (90 points) and the speed as the average speed of all their hits. Unpaired comparisons of means (t-test) were conducted between data from the two types of backhands for the variables stroke speed (km/h) and accuracy (%). The magnitude of the differences between values was also interpreted using the Cohen's d effect size (ES) (between-group differences (Cohen, 1988). Effect sizes are reported as: trivial (<0.2), small (0.2-0.49), medium (0.5-0.79), and large (≥0.8) (Cohen, 1988). In contrast, the ω_{peak} and IC of the different segments analysed did not follow a normal distribution. Therefore, a Mann-Whitney-Wilcoxon independent means comparison test was performed. The level of significance used was $p<0.05$. All statistical analyses were performed using the Origin 9 software program (OriginLab Northampton, MA), except the effect sizes that were calculated with the Psychometric freeware (Lenhard & Lenhard, 2016).

RESULTS

In table 1 we can see a comparison of the average speeds generated to the ball and the accuracy (%) of both types of backhands (SH and DH). Where despite the fact that the DH values are slightly higher for both average ball speed and accuracy, no significant differences were found between them ($P> 0.005$).

Table 1.
Comparison of average ball speed and accuracy between DH and SH of all participants.

Players **(SH)**	Ball speed *	Accuracy %	Players **(DH)**	Ball speed *	Accuracy %
1	103.2	61	1	90.8	32
2	104.4	33	2	103.2	58
3	89.6	37	3	96.9	35
4	103.9	46	4	87.9	43
5	96	52	5	76.9	31
6	82.5	52	6	82.5	45
7	94.3	43	7	82.8	36
8	92.3	40	8	87.5	60
9	81.1	34	9	92.3	36
10	98.9	42	10	90.1	43
Total	89.09 ± 7.52 *	42 ± 0.1 *	**Total**	94.62 ± 8.41*	44 ± 0.08*

* Means ± standard deviation; * Average ball speed

Figure 3 shows the comparison of the mean of ω_{peak} between DH and SH. Significantly higher ω_{peak} (rad / s) were obtained for the DH on the x axis of the sensors placed on the trunk and arm, and on the y axis of the sensor placed on the forearm. The effect size was large in the three cases (> 0.8). In the case of SH, ω_{peak} higher were obtained on the z axis of the sensors placed on the forearm and arm. Being in the case of the arm a moderate effect size (0.5-0.79) and in the forearm a large effect size.

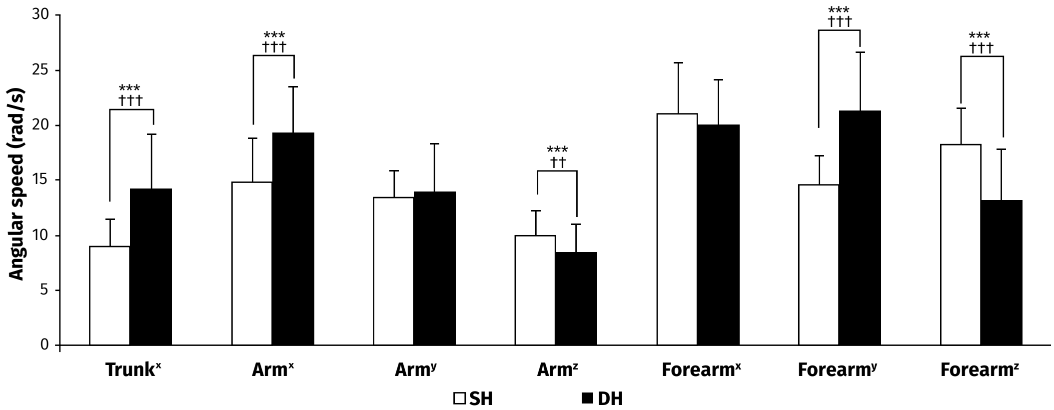

Figure 3. Comparison of the average of ω_{peak} between the two types of backhands on the different segments analysed (SH and DH). * p <0.025; ** p <0.01; *** p <0.001; * † small effect size; †† medium effect and ††† large effect.

Figure 4 represents the IC in relation to the temporal differences in the appearance of the ω_{peak} of the analysed segments, taking as reference $R\omega_{peak}$ of the sensor placed in the forearm, between DH and SH. Significant differences were found in the appearance of the ω_{peak} of the sensors placed on the arm and head between DH and SH. The effect size was small in both cases (0.2-0.4). There were no significant differences in the appearance of the ω_{peak} between DH and SH in the sensor placed in the trunk.

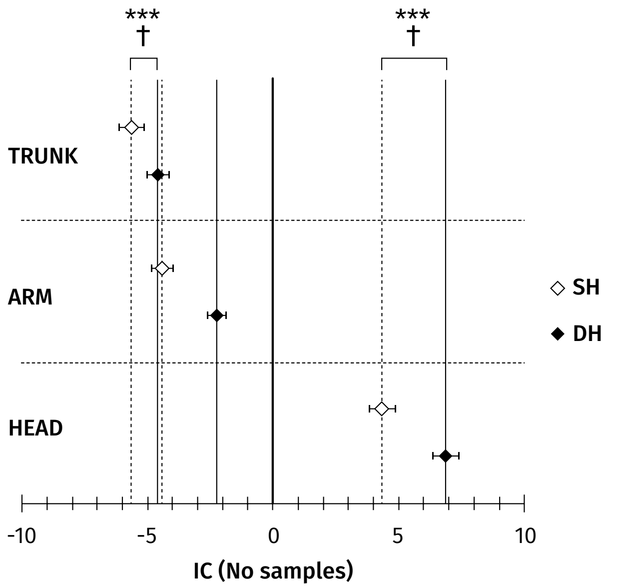

Figure 4. Comparison of the IC in the appearance of ω_{peak} in analysed segments taking as reference $R\omega_{peak}$ of the sensor placed in the forearm, between the DH and SH. Black rhombuses correspond to DH and white rhombuses with SH. * p <0.025; ** p <0.01; *** p <0.001; † small effect size (Fernandez-Fernandez et al., 2010).

DISCUSSION

Ball speed and accuracy

The average ball speed in SH was 89.09 ± 7.52 km/h while that in DH was 94.62 ± 8.41 km/h, although it is slightly higher in the DH no significant differences were found between them. Previous studies found that there are no differences in the ability to generate ball speed between DH and SH (Fanchiang et al., 2013). Regarding the accuracy obtained in the stroke performance test, no significant differences were found between DH and SH (42% vs 44%), which corroborates the results of previous studies (Muhamad et al., 2011; Stępień et al., 2011), which also did not find differences in accuracy comparing DH and SH. Both our results and of the literature consulted suggest that racket speed, ball speed and the accuracy of the stroke should not be affected by the type of backhand used; other factors such as kineanthropometry, coordination skill or player style will determine these variables (Reid & Elliott, 2002). Thus, our hypothesis is fulfilled since there are no significant differences in terms of ball speed and accuracy between DH and SH.

Angular Kinematic

In the present study biomechanical differences have been obtained in the ω_{peak} between DH and SH through the use of gyroscopes, which coincides with the results of the previous studies (Genevois et al., 2015; Giangarra et al., 1993; Reid & Elliott, 2002; Knudson & Blackwell, 1997; Choppin et al., 2011) in which similar differences were detected comparing both types of backhands by using 3D photogrammetry. Significantly larger ω_{peak} were obtained in the sensors placed on the trunk and arm on the x axis (rotational movements on the longitudinal axis) for DH, it is consistent with previous studies of Genovois et al. (2015) and Lo & Hsieh (2016) since both studies conclude that this type of backhand generates greater trunk rotation and external rotation of the arm and forearm compared to SH. They were also found ω_{peak} significantly larger for the sensor placed in the forearm on the y axis in the DH, but after reviewing the literature we have not found references that justify the finding. Instead, they were found greater ω_{peak} in the SH in the sensors placed on the arm and forearm on the z axis, which conforms to the results of Knudson & Blackwell (1997), Stępień et al (2011) and Reid & Elliot (2002) who detected a greater extension of the forearm accompanied by a higher termination in the technical gesture of the SH compared to the DH in a sample of competitive tennis players. In order to talk about anatomical movements based on ω_{peak} (captured with inertial sensors) in the different axes, we have to rely on the results of Choppin et al. (2011) that indicate that the angle between the face of the racket and the vertical is from 14 to 33 degrees. Taking into account the anatomy of the wrist, if the player will use an east grip or a little more closed such angle would make the forearm practically perpendicular to the ground, so that the y axis sensor would be parallel to the vertical and therefore a greater movement in z axis will indicate that the trajectory of the racket follows a path with greater vertical component (Kwon et al., 2017).

Intersegmental coordination

The comparison of the IC of the ω_{peak} between both types of backhand showed that both meet a sequential coordination between the different segments involved in the realization of the stroke (Allen et al., 2016). In addition, as in the study by Marshall and Elliott (2000) such sequential coordination occurs from proximal to distal in terms of angular speed and linear velocity for both, SH and DH. The point of maximum trunk rotation in the DH is significantly closer to the moment of maximum rotation of the forearm than in the SH, which could indicate that the hip begins to rotate earlier during two-handed backhand. The biomechanical differences found between DH and SH in terms of ω_{peak} and intersegmental coordination in some of the segments measured using gyroscopes confirm our initial hypothesis.

Head stabilization

In other sports where precision is an important factor, inertial sensors have been used to study the movements of the head (Fogt & Persson, 2017) but there are not many scientific studies about the movements of the head during a tennis stroke (Reid et al., 2013). Yet, gaze direction is a subject of great interest for tennis coaches (Lafont, 2008). In our study, there were significant differences in the moment of appearance of the ω_{peak} of the head. It is difficult to discuss these results since the movement of the neck depends to some extent on the movement of the trunk (*this needs to be further studied*). This ω_{peak} of the head during the impact could affect the movement control and the accuracy of the stroke, as can be deduced from the conclusions of the study by Lafont (2008), who revealed that elite players show a characteristic head fixation in the direction of the contact zone at impact and during the follow-through. It is not clear if this head fixation is more related to maintaining a stable head and body position during skill execution or to the need to extract operational information from the ball (Lafont, 2008).

LIMITATIONS

Five-marker model has been the most used with 3D photogrammetric systems to analyse biomechanical differences between DH and SH (Reid, 2001; Bahamonde, 2005; Reid & Elliott, 2002). In contrast, in our study with inertial sensors, four sensors have been used since the legs sensors were suppressed in order to capture only the kinematics differences of the upper body (Ahmadi et al., 2010). The results of the present study should be interpreted with caution because of possible errors when performing analysis of human movements (Akutagawa & Kojima, 2005). Placed instruments may also contain a source of error due to skin movement (Manal et al., 2003). Another limitation of the study was the number of participants used and their play level (intermediate). In future studies, the sample will be significantly increased and only competitive tennis players will be measured. In addition, it might be interesting for future studies to determine the maximum speed without to obtain a reference value. It could be that and athlete increases their accuracy at the expense of speed.

CONCLUSIONS

The proposed model of biomechanical analysis with gyroscopes is especially useful for the kinematic of tennis strokes during field-based experimentation and could easily be adapted to other hit sports with and without implements. It is also a low-cost and portable alternative that includes all instrumentation and data processing respect to others motion capture systems. Our hypothesis is fulfilled in the light of the results of the study. There are no significant differences between one-handed backhand and two-handed backhand in terms of speed and accuracy. Although it has been shown that there are significant biomechanical differences between two backhands, higher peak angular speeds were found in the trunk and arm over the x axis in two-handed backhand, which could indicate that this type of backhand generates greater trunk rotation and external rotation of the arm and forearm compared to SH. The peak angular speeds were greater in the arm and forearm on the z axis in the case of one-handed backhand which is related to a greater extension of the forearm accompanied by a higher termination in the technical gesture. Both types of backhands followed a sequential coordination from proximal to distal, but in the two-handed backhand the moment of maximum trunk rotation was located significantly closer to the point of maximum rotation of the forearm compared with one-handed backhand.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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