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Research article

The Variability of The Serve Toss in Tennis Under the Influence of Artificial Crosswind

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Abstract

This study was made to analyze the variability and stability of the serve toss in tennis, on the *x* (side-to-side), *y* (back-to-front) and *z* (vertical) axes, with 12 experienced players under the influence of crosswind (induced aerodynamic flow) produced by an industrial ventilator. The players were analyzed individually after serving at maximum speed and accuracy to the intersection point of the centre line and service line ("T" point). The results allow us to conclude that the experienced players tend to stabilize the vertical dimension of the service (*z* axis). Additionally, this study confirms the invariability of the player height ratio: height of impact (1:1.5) in experienced players even when constrained by the "artificial crosswind." Given the above, the vertical dimension of the tennis serve is assumed as a constant feature, which is guaranteed in the remaining varying dimensions (*y* and *x* axes) of the ball toss. Thus, the variability should be seen as part of the solution and not as something to be avoided by players and coaches.

Key words: Variability, tennis serve, performance, crosswind, motor control.

Introduction

The stability and consistency of the tennis serve motion is considered to be determinant in the player's performance (Forti, 1995; Bollettieri, 2001; RFET, 2003). According to Bahamonde (2000) and Girard et al. (2005) the tennis serve is the most important stroke, and also the most complex, when compared with other movements in tennis. Within the scope of motor variability, the tennis serve has recently been attracting some investigative interest (Menayo et al. 2012; Mendes et al., 2012; Reid et al., 2010). In this perspective, Elliott et al. (2009) extol some constant features in the serve such as the timing, the magnitude peak of the knee flexion or the stability of the ratio of the player height: impact height (1:1.5).

The stabilization of the *z* axis (vertical) in the ball toss is another relevant invariable characteristic of the movement. Davids et al. (1999), Bennett et al. (2001) and Handford (2006) found that in volleyball serve, this stabilization resulted from a process of compensatory variability of the *x* (side to side) and *y* (back to front) axes. These results contradict the idea that the consistency of the motor pattern should be assumed as a primary goal in organizing and practicing schedule (*e.g.*, Forti, 1995).

Given the similarity between volleyball and tennis serves, the analysis of the ball toss in the tennis serve is justified by the influence it has on the performance level of this movement (Elliott et al., 2009; Fuentes and Menayo, 2009).

Although this is the movement that most depends on the player -when compared with other tennis movements- it is also influenced by other types of constraints throughout a tennis match, from which emerge environmental factors such as the wind or rain.

In this perspective, bearing in mind Karl Newell's (1986) theoretical environmental constraints model, according to the characteristics of the practitioner and the task, they take a leading role in the serve performance.

The relevance of the wind in the tennis player's performance is enhanced by several authors (Elliott et al., 2009; Faulkner, 1997; Flanagan, 1983; Hoskins, 2003; Loehr, 1996) with no scientifically based opinion. In this context, Brody (1987), Scott and Randy (2000) and the American Sport Education Program (2009) analyzed the importance of the three wind directions in tennis serve: favorably (behind the server), against and lateral or cross. In this regard, the previous study carried out by Mendes et al (2011a) with experienced tennis coaches concluded that the wind is the most important environmental constraint in the tennis serve performance. On the other hand, there are few publications that analyze the variability of the ball toss in tennis serve (Reid et al., 2010). Therefore, we considered relevant to conduct this type of analysis with experienced tennis players under the effect of crosswind.

The present work aimed to verify if the invariant characteristic, vertical dimension of the ball throw in volleyball serve, evidenced by Davids et al. (1999), Bennett et al. (2001) and Handford (2006), was also confirmed in the tennis serve. Moreover, we intended to analyze if this invariant was observed under the influence of a relevant extrinsic constraint in tennis serve, the crosswind. For that purpose, we simulated this environmental factor with an industrial ventilator in the tennis court. Another objective of this study was to analyze the ratio between the player's height and the height of the player's impact point, with and without the environmental constraints (*i.e.*, Induced Aerodynamic Flow or artificial crosswind).

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Methods

Sample

Twelve male, right-handed players participated in this study with an average of 25.2 ± 3.9 years old. The anthropometric characteristics of this group of players were as follows: height 1.77 ± 0.06 m, wingspan of 1.81 ± 0.05 m and body mass of 72.3 ± 4.2 kg.

All players have been practicing tennis for 16.3 ± 5.6 years, from which 13.7 ± 4.3 years were on competitive national tennis. The study was conducted according to the Ethics code of the University of Coimbra and the recommendations of the Helsinki Declaration on Research with Human Beings.

Task

The movement required was the flat serve from behind the base line of the tennis court, on the right-hand side and 80 cm away from the central mark. The indoor tennis court had the regulation dimensions for a singles game, 2377 cm long and 823 cm wide. All the participants were asked to serve at maximum speed and accuracy targeting the point of intersection of the centre line and service line ("T" point).

Experimental set up

All the tennis players performed 20 free serves (without instructional or wind constraints), called IAF0 (a control condition), and then performed four sets of 20 serves under different practice conditions: (1) minimum IAF speed of 2.4 $m \cdot s^{-1}$ (called IAF1); (2) medium IAF speed of 4.3 $m \cdot s^{-1}$ (called IAF2), 3); (3) maximum IAF speed of 5.8 $m \cdot s^{-1}$ (called IAF3) and; (4) random IAF speed with random sequences of all three IAF speeds (called IAFr). Therefore, there was a total of 100 serves.

In this study, we analyzed the variation of the three points (Initial, peak an impact) on the ball toss, and both were measured based on the position of the ball in the 3 axes (3D analysis).

Induced Aerodynamic Flow device

The production of the IAF device was adapted from an industrial helical ventilator METEC - HCT - 45 - 4T. The speed of the engine was set up using an electronic device (SEW Eurodrive) installed in the ventilator coupled with an 11 positions potentiometer. In order to regulate the air flow, a steel mesh of 0.45 cm and a conduct of 120 cm length and 45 cm diameter (see also Mendes et al., 2011b) were placed in the ventilator output.

The players' height varied. Therefore, they threw the ball at different heights. The ventilator had a diameter of 45 cm, so a telescopic lift GUILE ELC – 506 was used to adjust the height of the ventilator up to a maximum of 520 cm. The calibration of the ventilator for each tennis player was made based on a preliminary study which consisted in analyzing the average of the highest point of the ball in 20 serves and determining its impact point (see details on "Device for analysis of the ball toss" described below).

The ventilator had a stable air flow rate of 60 cm diameter, independently of the position of the potentiometer. It was stipulated that the upper edge of the conduct would be positioned at the average level of the highest point reached by the ball during the toss.

Device to analyze the ball toss

The recording of the initial (I), peak (PP) and impact point (IP) were obtained from two cameras: (1) a camera in the sagittal plane of the tennis player: Casio Exilim Pro EX-F1, shooting at 210 Hz, positioned 700.5 cm away from the service mark and fixed on a tripod 206.5 cm high and (2) a camera in the frontal plane, positioned behind the player: Casio EX-FH25, shooting at 210 Hz, positioned 363 cm away from the tennis player and fixed on a tripod 263cm high. The timing of the beginning of the footage for each of the two cameras was synchronized by the connection and visualization of a LED per camera.

A 3D analysis of the collected images was carried out, with a maximum error of 1cm, i.e., the farthest plane from the camera presented a resolution of 1cm^2 per pixel (Figure 1). The space was calibrated with a square base parallelepiped of 250 cm edge and 320 cm height, giving a reference system of eight points in space (Mendes et al., 2012) using Matlab2009R. A script, which included the capture of images related to the three points analyzed (I, PP, IP), was developed for the calculation of the positions and their coordinates (x, y, z). According to the studies of Reid et al. (2010), we chose the position of the left foot at the beginning of the serve as the origin of the reference system, i.e., 0.80 cm away from the central mark of the court. After capturing the service, the physical space was calibrated using direct linear transformation (*DLT*), which transforms the position of the tennis ball in pixels into the metric space, thus obtaining the Cartesian positioning of the tennis ball over time. For a more detailed description of the 3D analysis, please refer to Mendes et al. (2012).

Figure 1. Three-dimensional reference system for the analysis of the toss ball in three points (x, y, z): Initial, Peak point and impact point of the players.

Procedures

The purpose of the task was explained to the players: to serve at maximum speed and accuracy targeting the intersection point between the centre line and the service line ("T" point). Players were assessed individually. In order to prepare the participants for the task, each had a five minute warm-up followed by a period of five minutes to perform eight serves at increasing intensity: the first four serves were with low intensity, the following two serves with medium intensity and the last two serves with full intensity. During all the procedures, including data collection, players did not receive any verbal information on the quality of the movement or the outcome of the test.

The players served 100 times in five different conditions. In the first series of 20 serves the players served without IAF and then, they served 20 times in each condition in a counterbalance of the four following conditions: minimum, medium, maximum and random speeds (i.e., variation of the three speeds of IAF). They had a recovery time of 20 seconds between the serves or trials and 180 seconds between the 5 different conditions (following the rules of change between court sides).

Statistical analysis

The analysis of the variability of the 3 points of the toss ball was done axis by axis, that is, in a one-dimensional way. The variability was measured using the standard deviation (SD) and the coefficient of variation (CV).

Also, following the conjecture of a one-dimensional analysis (axis by axis), the statistically significant differences between the 5 conditions of practice for each player (intra-individual analysis) in the three points of the ball toss, were analyzed with the ANOVA one-way test. The Scheffé post hoc test was used if the assumptions of normality and homogeneity were verified. When the assumption of homogeneity was not observed, the Games-Howell post hoc test was used (Vicent, 1999). As the samples were below 30, the assumption of normality was verified using the Shapiro-Wilk test (Marôco, 2010; Pallant, 2011). In cases of non-verification of normality, the following equation was used to the analysis of the symmetry (Gageiro and Pestana, 2005, p.288):

$$\left|\frac{\text{Skewness}}{\text{Std errorSkewness}}\right| \leq 1{,}96 \qquad (1)$$

The Levene's test was used to verify the assumption of homogeneity of One-way ANOVA. This analysis was performed using the IBM program SPSS (version 19) for a significance level of 5%. Estimates of the effect sizes, $\eta 2$, i.e., the proportion of variation of the independent variable which is explained by the dependent variable (Marôco, 2010, Pallant, 2011) and the power of the test were determined.

In order to graphically represent the differences between the conditions of the practice in the 3 positions of the ball toss for the serve, bi-dimensional tools were used — the error ellipses. These represent in the same way the maximum direction and the minimum direction of the errors, the standard deviation of the axes that form the plane and the distribution (i.e. variability) throughout the area of the ellipse (cf. Darling and Cooke, 1987). Observing the shape, area orientation of the ellipse, it is possible to make comparisons between players and practice conditions in a quick and significant way.

To value the influence of the constraint during the throw, *i.e.*, in the I, PP and IP points, references to the center of the error ellipses on the peak and impact point in the frontal plane (*xOz*) were done, thereby observing the presence or absence of displacement of the cloud point (set of trials per condition of practice), from left to the right (IAF direction).

Results

Concerning the Initial point (I), players showed average values in the *x* axis (side-to-side), between 2.60 cm (IAF0 in the player 5) and 47.95 cm (IAF0 in the player 2). In the *y* axis (back-to-front) the variation was lower, 6.86 cm (IAF3, player 3) to 38.57 cm (IAFr, player 4). In the z axis (vertical), the variation of the average values was even lower, being situated between 165.20 cm (IAF0, player 12) and 194.16 cm (IAF, player 2). A tendency towards the stabilization of the z axis (vertical), was common on all players, with SD values always lower than 5 cm, in all practice conditions. On the other hand, in some players the SD values indicate a higher variability in the *y* (players 1, 4, 6, 8) and *x* (players 1, 4, 7 and 10) axes with values up to 5 cm.

Regarding the second point, Peak Point, average values for the *x* axis varied between 3.14 cm (IAF2, player 6) and 22.91 cm (IAF0, player 5). For the *y* axis, the average ranged from 20.47 cm (IAF0, player 11) to 82.68 cm (IAF1, player 6), and in the *z* axis the averages varied from 252.97 cm (IAF1, player 6) to 366.13 cm (IAF2, player1). The players remained stable on the *z* axis, with SD values not higher than 10 cm. Moreover, the players showed in the *y* axis, SD values between 2.70 cm (IAFr, player 2) and 12.82 cm and in the *x* axis SD values varied from 2.17 cm (IAF1, player 11) to 10.53 cm (IAF0, player 5).

As for the IP, the *x* axis average values varied from 3.51 cm (IAF1 in the player 2) to 37.54 cm (IAF in the player 7), 8.60 cm (IAF2 in the player 11) to 86.73 cm (IAF1 in the player 6) in the *y* axis, and in the z axis the values ranged between 243.76 cm (IAF in the player 8) and 269.04 cm (IAF1 in the player 1). The players maintained stability in the *z* axis, with SD values lower than 5 cm. The *x* axis showed SD values from 3.64 cm (IAF3 in the player 11) to 18.02 cm (IAF0 in the player 2) and in the *y* axis, SD values varied between 2.70 cm (IAFr in the player 2) and 19.08 cm (IAF0 in the player 5). Moreover, SD values in some players indicate a higher dispersion in the *y* (players 1, 5 e 10) and *x* (Players 3, 5, 7 e 12) axes with values higher than 10 cm.

The inter-individual analysis showed in the Initial Point (I), a higher dispersion of the data (SD values) for the *x* axis in all the practice conditions, except in the IAF2. For the PP, SD values varied more in absolute terms, in the *z* axis. However, and comparing with others axes, the average values were much higher in the *z* axis. Given the fact that players had different heights, the inter-individual SD values were higher, comparing with the intra-individual SD values. In the IP, SD values were higher in the *x* axis in four practice conditions, IAF0, IAF1, IAF2 and IAFr (cf. Table 1).

Apart from the variability of the point cloud analyzed in the 3 positions of the toss ball, it was important

Table 1. **Mean and standard deviation of the 3 points of the toss ball, on the 12 players per condition of practice in the 3 axes: *x, y* and *z*.**

N = 240		I			PP			IP		
		x	y	z	x	y	z	x	y	z
IAF0	**M**	26.08	17.63	180.20	5.53	40.96	297.97	17.98	50.06	261.21
	SD	17.16	12.63	8.12	15.78	15.22	28.13	19.01	14.89	6.99
IAF1	**M**	26.79	18.81	180.69	4.27	43.94	294.81	15.64	54.07	259.40
	SD	15.81	11.27	7.26	14.49	17.64	29.59	18.35	17.53	7.38
IAF2	**M**	18.29	25.11	181.04	4.22	43.54	297.34	13.50	54.42	261.21
	SD	11.92	15.63	6.96	13.49	14.83	28.08	17.53	14.97	7.59
IAF3	**M**	27.33	16.83	180.24	0.46	38.04	297.93	6.18	47.69	261.01
	SD	17.40	8.06	8.64	13.45	13.71	29.70	14.28	15.23	9.39
IAFr	**M**	25.97	19.11	181.52	4.16	43.25	299.91	14.16	54.26	261.36
	SD	14.21	11.34	6.16	13.13	13.88	29.16	17.73	15.24	7.40

to verify whether or not there was shift of the points between the five conditions of practice. The IAF had a statistically significant effect size albeit of small dimension over the Initial to the *y* axis [$F_{(4,1195)}$=6.092, *p-value*=0.001, η^2=0.020, power=0.987] and in the PM on the *x* axis [$F_{(4,1195)}$=4.702, *p-value*=0.001, η^2=0.015, power= 0.952]. Statistically significant differences in the PI on the *x* axis [$F_{(4,1195)}$=16.390, *p-value*=0.001, η^2=0.052, power =1.0] presented a medium effect size.

Comparing the practice conditions, we verified that in the variable Initial, the IAF1 (*p-value*=0.008), the IAF3 (*p-value*=0.029) and the IAFr (*p-value*=0.001) showed higher values than the IAF0 condition, that is, players tended to drop the ball ahead (*y* axis). Concerning the PP, we observed that the IAF3 (*p-value*=0.008), compared to the EAI0 condition, showed higher values in the *x* axis. In this axis and for the IP variable, higher values were observed in the IAF2 conditions (*p-value*=0.045) and EAI3 (*p-value*=0.001). That is, when confronted with a "stronger crosswind", players had a more distant PP and IP from the ventilator.

According to the calculation of the center of the ellipses by practice condition on the *xOz* plane, it is perceptible in this bi-dimensional analysis the gradual shift of the point cloud in the presence of IAF. The following image shows the ellipses and respective centers of player 5 on PP and IP (Figure 2).

As for the centers of the ellipses (Figure 3), only the abscissa (*x*) coordinates are represented, since the applicate coordinates (*z*) have a high stability in the five conditions of practice, as noted above.

The *z* axis' (vertical) lower variability observed in all players on all conditions of practice was also found when comparing practice conditions and players. By normalizing the average height of the impact point height (H_{impact}) of each player, it was found that players perform the impact at 147.78% (cf. Table 1). Only the player 6 with a H_{impact} of 141.09% and the player 11 with an H_{impact} of 153.76%, moved slightly away from the ratio found by Girard et al. (2007) and Elliott et al. (2009). The CV values showed a high stability of the place of the impact point (normalized height) in all players, even in the presence of IAF (cf. Table 2).

Discussion

This work aimed to verify if the invariant characteristic of the vertical dimension of the ball toss in volleyball serve was confirmed in the tennis serve, i.e. in the presence or absence of IAF constraint, that is, artificial crosswind. In addition, we also sought to examine the height ratio of the player, when the impact point was kept 1:1.5, even in the presence of IAF.

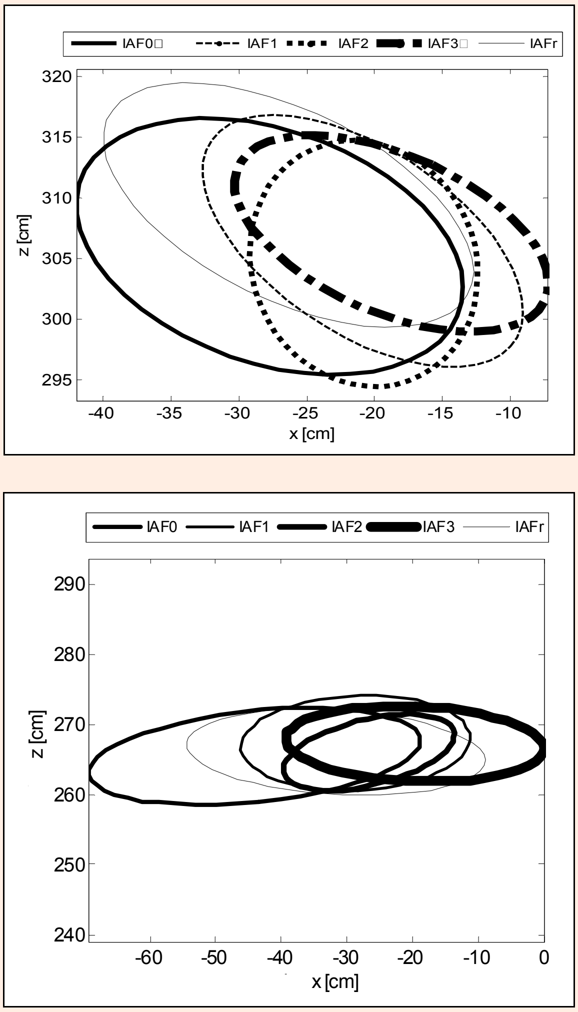

Figure 2. **Ellipses in the *xOz* plane by condition of practice for player 5 in the PP (top) and IP (bottom).**

The results proved that tennis players when serving without any constraints (IAF0), showed a higher stability or consistency of the *z* axis and a higher inconsistency in the *x* and *y* axes, during the ball toss (Initial and Impact points). The stabilization of the *z* axis within the ball toss, corroborates the results found by Davids et al. (1999), Bennett et al. (2001) and Handford (2006) for the overhand volleyball serve. Furthermore, Reid et al. (2011) analyzed the first and second serve depending on the type of target zone (*i.e.*, "T" point, "receiver´s body", and wide) of six elite players, also verifying a higher consistency in the *z* axis within the peak and impact points. In this context, the *x* axis (side-to-side) was the one who showed the largest variability.

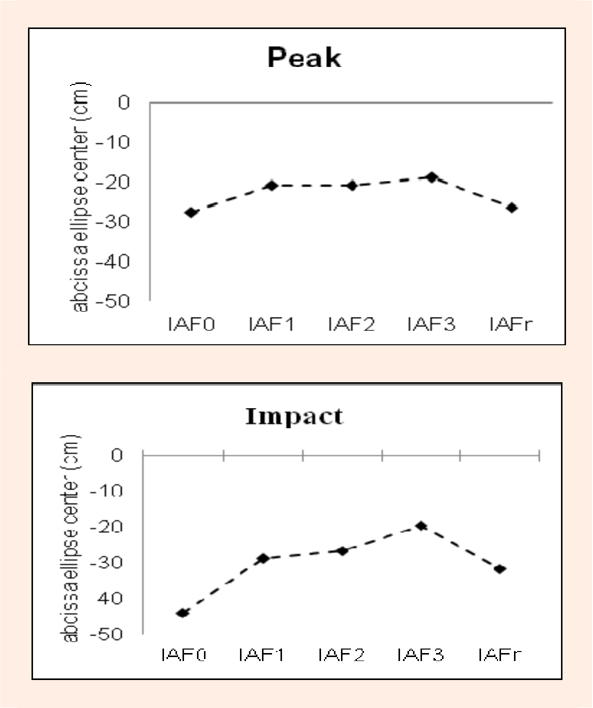

Figure 3. The abscissa ellipse center (cm), the peak and impact point, in the *xOz* plane of the player 5, by condition of practice. The 0 point indicates the origin of the reference system, where the higher values deviate from the ventilator and the lower values are closer to it.

The inconsistency observed in players' behavior in the *x* and *y* axes during the Initial and Impact Point, both in the condition without wind (IAF0) and in other conditions with wind (IAF1, IAF2, IAF3 and IAFr), looks tolerable and irrelevant for the success in tennis serve. Given the data, we can assume that experienced players tend to stabilize the *z* axis and, on the other hand, tend to present some variability in the remaining axes within the serve.

A dominant tendency in tennis training (Bollettieri, 2001; Mcgehee, 1997; RFET, 2003) is to stabilize the three axes according to an analytical or fractionated training perspective. In other words, the approach to the ball toss in the serve in which we favor consistency in height, depth and laterality, as is the case of the ball toss without impact, can compromise the invariant characteristic of the tennis serve, *i.e.* its vertical dimension. According to Reid et al. (2010), such coaching methods based on the decomposition of the movement are still common within tennis coaches.

Regarding the analysis of the players' height impact point (H_{impact}), the values obtained by Girard et al. (2007) with competition players were confirmed, i.e., a player height ratio: impact height of approximately 1:1.5. It should be noted, in this context, that Elliott et al. (2009) described the stability of this ratio during the morphologic growth of young players (the practitioner's constraint) and given the changes of the task that entails the training itself(*i.e.*, type of racket, height of the tennis court net).

These results confirm the maintenance of this ratio in experienced players, even when constrained by "artificial crosswind". Thus, stabilization of the players' H_{impact} at approximately 150%, even considering that they are under the influence of their individual heights, the task and the physical environment constraints (*e.g.*, crosswind), makes of this invariant characteristic a decisive element in the serve performance.

The impact of the crosswind constraint (IAF) on the tennis serve performance of the analyzed players was measured in a previous study (Mendes et al., 2012). In this work, no differences were observed on the accuracy and precision with constant (IAF1, IAF2, IAF3) and random crosswind (IAFr). Therefore, it seems that the variation noted in the *x* and *y* axes "was not enough" to produced statistical differences in the serve's accuracy and precision.

Conclusion

This study confirmed the stabilization of the *z* axis

Table 2. Averages of the impact point height normalized to the standing height of the 12 players by practice condition, averages and correspondent coefficients of variation of the 5 practice conditions.

players	Standing height	H_{impact} (%)					Mean	CV
		IAF0	IAF1	IAF2	IAF3	IAFr		
1	184.70	144.93	145.66	145.31	143.59	143.12	144.52	0.007
2	180.20	146.58	146.12	147.19	147.65	146.92	146.89	0.004
3	184.90	144.38	144.79	145.17	146.65	144.66	145.13	0.006
4	179.30	148.41	144.82	149.08	146.79	148.95	147.61	0.011
5	178.55	149.94	149.99	149.77	150.53	149.98	150.04	0.002
6	180.65	142.66	139.65	140.27	141.89	140.99	141.09	0.008
7	172.75	148.39	147.13	147.62	149.22	148.32	148.14	0.005
8	169.25	147.45	148.01	148.72	144.02	148.62	147.36	0.012
9	174.80	150.12	150.39	150.87	151.22	150.84	150.69	0.003
10	176.75	149.59	148.82	149.74	151.29	148.56	149.60	0.006
11	173.25	155.14	152.80	153.54	153.51	153.79	153.76	0.005
12	167.55	149.94	146.84	148.65	148.86	148.50	148.56	0.007

(vertical) of the ball toss in the tennis serve without IAF (IAF0) as well as the four conditions with IAF (IAF1, IAF2, IAF3 and IAFr). To allow the players the stabilization the *z* axis, they had to vary in the *y* (back-to-front) and *x* axes (side-to-side).

The maintenance of a player height ratio: impact height of approximately 1:1.5 in experienced players, even when constrained by "artificial crosswind", reinforces the importance of this variable for the success in tennis serve.

Regarding the application of these aspects in a sports context, the training of tennis serve, by being directed to the consistency of the *z* axis within the ball toss can promote the variability of the other two axes (*x* and *y*).

As future research, the development of an experimental set up that induces the wind direction and randomness will allow us gain a better ecological validity. Finally, the use of non-linear measures of variability and the increase of the number of participants in future studies would also strengthen this line of research.

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Key points

- Analysis of the tennis serve variability under the effect of artificial crosswind
- Twelve experienced tennis players performed a set of 20 free serves (without wind constraints), and four other sets of 20 serves under different practice conditions (with different crosswind intensities)
- The players tend to stabilize in the z axis and vary in the y- (back-to-front) and x-axes (side-to-side) during the ball toss tennis serve in all the practice conditions (with and without crosswind)
- The maintenance of a player height ratio: impact height of approximately 1:1.5 in experienced players, even when constrained by "artificial crosswind".

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