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Original Article

Disparities in ground reaction forces between serve types in young male and female tennis athletes.

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Abstract:
Analyzing forces exerted during sports movements provides valuable insights for athletes and coaches, aiding in understanding sports performance and enabling targeted training. In tennis, the serve is the most complex yet crucial stroke. This study aimed to measure and explore potential differences in forces exerted on the force platform using the "foot back" technique during three distinct serve types—flat, slice, and topspin—in young tennis players aged 12–16 years. Eleven right-handed junior tennis players (5 males and 6 females) participated in the study. A KISTLER force platform (Type: 9281CA, sampling frequency of 1000 Hz) was employed to capture ground reaction forces. Subjects performed three attempts for each serve type, with the ball immobilized on a stand to maintain an optimal height for racket contact in the air. From the recorded data, the maximum forces (fx, fy, and fz) of the three different serve types—flat, slice, and topspin—were assessed using BioWare® Software Type 2812A at three critical moments of the jump: the beginning of the upward movement of the body, the start of take-off, and the moment of landing on the force platform. The findings indicated that forces were highest in all three serve types during the initiation of take-off. Vertical force fz was also consistently greater at all jump stages across all serve types. Analysis of variance revealed a statistically significant relationship between the factors "serve" and "time." The initiation of the upward body movement occurred earlier in the topspin serve, followed by the slice and, finally, the flat. The take-off began earlier in the slice serve, followed by the topspin, and was later in the flat. In terms of time, the moment of landing occurred first in the slice serve, followed by the topspin, and was recorded as the slowest in the flat. Studying the forces exerted during the serve execution can benefit both athletes and coaches, enhancing results during the kinetic chain's initiation phase and providing a solid foundation for effective "leg drive," leading to more dynamic serves, improved technique, and potentially reduced risk of injury.
Key Words: **Ground reaction force, tennis serves, young tennis athletes**.

Introduction

Since a successful serve is the result of the sum of the forces that start at the ground and are transferred up through the kinetic chain to the contact of the racket with the ball, the speed of the serve depends on the maximum muscle strength during the charging stage (Elliot, Marshall, & Noffal, 1995). The "leg drive" mechanism is an important factor in the efficiency and speed of the serve (Reid, Elliot & Alderson, 2008). By improving footwork, a better "leg drive" can be produced, which can enhance shoulder rotation and result in better service (Girard, Micallef, & Millet, 2005). The ground reaction forces created in the loading phase lead to a thrust that lifts the racket of the dominant side through the upper arm, resulting in the racket reaching a greater height (Bahamonde, 2000). The location of the cocking stage depends on how effective the loading stage is (Kovacs, & Ellenbecker, 2011). Between the loading stage and the beginning of the cocking and acceleration stage, there is an increase in vertical ground reaction forces (Bahamonde, & Knudson 2001). It is therefore important to understand the differences in the forces exerted on the three basic types of serve, flat, slice, and topspin, and how these can affect the kinetic chain. In an efficiently functioning kinetic chain, the legs and trunk are the "drivers" for force development and the basis for upper body mobility (Elliot, Marshall & Noffal, 1995; Kibbler, 1995). Differences presented in the maximum vertical force among the three serve types were few, with flat service taking the lead compared to slice and topspin serves. This is because flat service is the first service and is executed at higher velocities compared to the other two, and when young athletes execute it they exert higher maximum force (Mourtzios, et, al.,2021).

Many researchers have investigated the differences in the three basic serves in tennis. References focused on the plantar pressure differences (Mourtzios et al., 2019) showed that the technique applied, mainly to the footwork, varies between types of serves. So, each type of the three serves has different loads. Differences were presented (Mourtzios et al., 2019) in ankle and knee joint kinematics between the flat, slice, and topspin tennis

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serves. Lin, J., Song, J., & Sun, L. (2022) reported that the main difference between the types of tennis power serving techniques is that the body obtains different ground reaction forces in all directions. Chow et al. (2009) found that all lower trunk muscles showed their highest EMG values during the acceleration phase of the three types of tennis serves. Mourtzios et al. (2021) reported kinematic differences between professionals and young players in tennis serves. Girard et al. (2012) aimed to examine the impact of prolonged tennis playing on stroke velocity and peak vertical forces during first (flat and slice) and second (topspin) serves.

From a review of the literature it is clear that few works have dealt with ground reaction forces in service performance (Elliot & Wood, (1983); Van Gheluwe & Hebbelllink, (1986); Lo, Wang, Wu & Su, (2001), Bahamonde & Knudson, (2001); Girard, Micallef, & Millet, (2005), while no studies were found that examined the execution of the three basic types of serves in young tennis players. The purpose of this study was to measure and examine the differences in ground reaction forces that may exist between the three different types of serve, flat, slice, and topspin.

Material & methods

Participants

Eleven right-handed junior tennis players, ages 12 to 16, who compete in events run by the Hellenic Tennis Federation and are placed at the top of the national list, participated in this study (5 males and 6 females). With training experience ranging from seven to eleven years, they participated in a 12±2 hour weekly tennis-specific training program (technical, tactical, and physical condition). Their ages ranged from 14,4±1,33 years, and their heights and weights were 170,6±12,14 cm and 55,80±12,17 kg, respectively.

Before participating in the study, all participants were questioned about whether they had experienced any musculoskeletal injuries or other issues. The ethics committee of the Faculty of Sport Science at The Aristotle University of Thessaloniki approved this study, and all methods followed the advice and principles outlined in the Declaration of Helsinki. Before participating, both participants and parents supplied written informed consent after being fully informed of all experimental methods.

Procedures

The measurement was carried out in the Neuromechanics laboratory of TEFAA Serres. Subjects performed a standardized warm-up followed by a 10-minute performance of all three different serve types. They performed three attempts for each type of serve with the ball immobilized on a stand so that it was ready in the air at an optimal height for racket contact. From these, the best effort was selected based on the smooth curve of the vertical force. The feet were on the force platform dyno throughout the execution of the serves. From the recordings, the maximum forces fx, fy, and fz of the three different serve types flat, slice, and topspin were evaluated with BioWare® Software Type 2812A at three different moments of the jump, the beginning of the upward movement of the body, the beginning of the take-off and the moment of landing on the force platform.

Instruments

A KISTLER force platform (Type: 9281CA, sampling frequency: 1000 Hz) was used to measure the ground reaction forces, which is equipped with four piezoelectric transducers. To take full advantage of the characteristics of the piezoelectric crystals, the dynamic floor was placed on the ground using a special suspension frame (Mounting Frame, 9423), which was concreted into the ground. The electrical charge produced in the piezoelectric transducers, due to the external pressure, was transferred through a coaxial cable (168IB5) to a charge amplifier (5233A2). The recording of the forces concerned both the vertical component and the two horizontal components.

Statistical Analysis

The statistical package SPSS 25.0 for Windows was used for the statistical analysis of the data. The level of significance was set at P<0.05. The standard deviation was calculated for all variables. An analysis of variance (Repeated Measures Anova) was used to find out possible statistically significant differences with independent variables in the three basic types of service (flat, slice, and topspin), the three different times of the jump (beginning of the upward movement of the body, start of take-off, and moment of landing), with repeated factors and dependent variables the maximum forces 'fx', 'fy', and 'fz' and contact time.

Results

The descriptive data of the forces in the different conditions are shown in Table 1. The analysis of variance showed no statistically significant interaction of "service" X "jump time" X "forces" (p>0.05). The analysis of variance showed a statistically significant interaction of the factors "jump time" X "forces", as shown in Fig. 1 ($F_{37,\ 15}$ = 0.00, p<0.05), where the forces applied during the execution of the three different serves vary significantly during jump times. The analysis of variance did not show a statistically significant interaction between the factors "service" X "jump time", nor of the factors "service" X "forces". A statistically significant main effect of the factor "jump time" was found, $F_{89,74}$= 0.00, p<0.05, where forces are greater in all three serves at the time of takeoff initiation. Also, the analysis of variance showed a statistically significant effect of the factor "forces", ($F_{23,17}$= 0.00, p<0.05), where the vertical force fz is greater at all times of the jump in the three different types of serves.

Table 1. Mean (± standard deviation) of horizontal (fx), lateral (fy), and vertical (fz) forces in the three types of serve. For each serve, values at the start (LOW), highest point of ball impact (HIGH), and take off (TAKE OFF) are shown.

FORCES	SERVES	(N)
fx	FLAT LOW	-12±18
	FLAT HIGH	-9±43
	FLAT TAKE OFF	23±45
	SLICE LOW	-14±13
	SLICE HIGH	-25±81
	SLICE TAKE OFF	-16±82
	TSPIN LOW	-16±19
	TSPIN HIGH	-9±52
	TPSPIN TAKE OFF	-13±83
fy	FLAT LOW	14±37
	FLAT HIGH	15±41
	FLAT TAKE OFF	118±100
	SLICE LOW	26±26
	SLICE HIGH	-25±89
	SLICE TAKE OFF	133±170
	TSPIN LOW	29±27
	TSPIN HIGH	8±62
	TPSPIN TAKE OFF	201±179
fz	FLAT LOW	354±163
	FLAT HIGH	1117±393
	FLAT TAKE OFF	1078±622
	SLICE LOW	370±226
	SLICE HIGH	1083±406
	SLICE TAKE OFF	1078±521
	TSPIN LOW	386±115
	TSPIN HIGH	1171±298
	TPSPIN TAKE OFF	1153±542

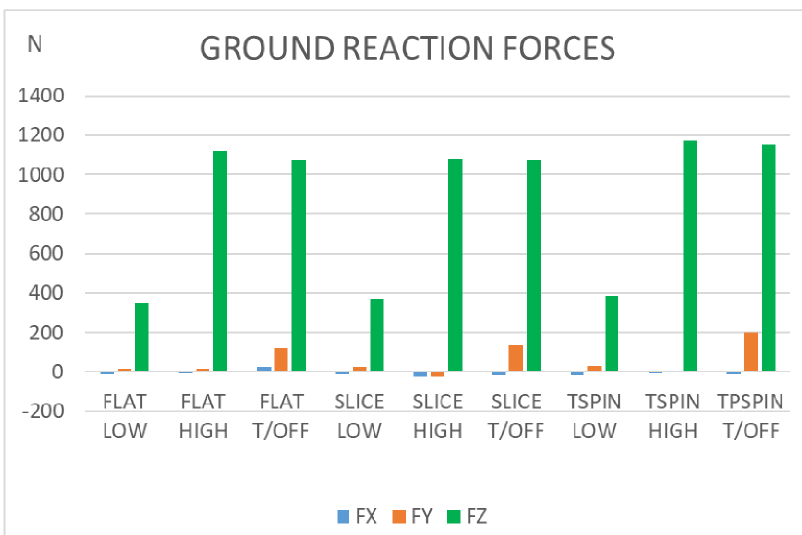

Fig. 1: The forces fx, fy, fz in the three different serves flat, slice, and topspin, at the three times of the jump.

Descriptive data on the time taken for the various execution steps in the different conditions is presented in Table 2. The analysis of variance did not show a statistically significant "service" X "jump time" X "time" interaction ($p>0.05$). A statistically significant interaction of the factors "service" X "time" was found, as shown in Figure 2 ($F_{2,85}= 0.03$, $p<0.05$), where the start time of the upward movement of the body is earlier in topspin, then in slice, and finally in flat. Then the take-off starts earlier in the slice, then topspin, and later in the flat. In terms of time, the moment of landing precedes the slice serve, followed by the topspin serve, and then the slowest in the flat serve. The analysis of variance did not show a statistically significant interaction of the factors "service" X "jump time moment", nor of the factors "time moment" X "time". Analysis of variance showed a statistically significant main effect of the factor “time”, ($F_{239,96}= 0.00$, $p<0.05$) as shown in Fig. 2.

Table 2: Execution time of the three serves.

TIME	SERVES	(s)
	FLAT LOW	0,35±0,17
	FLAT HIGH	0,72±0,18
	FLAT TAKE OFF	1,16±0,24
	SLICE LOW	0,29±0,14
	SLICE HIGH	0,60±0,20
	SLICE TAKE OFF	1,04±0,22
	TSPIN LOW	0,28±0,14
	TSPIN HIGH	0,70±0,17
	TPSPIN TAKE OFF	1,15±0,24

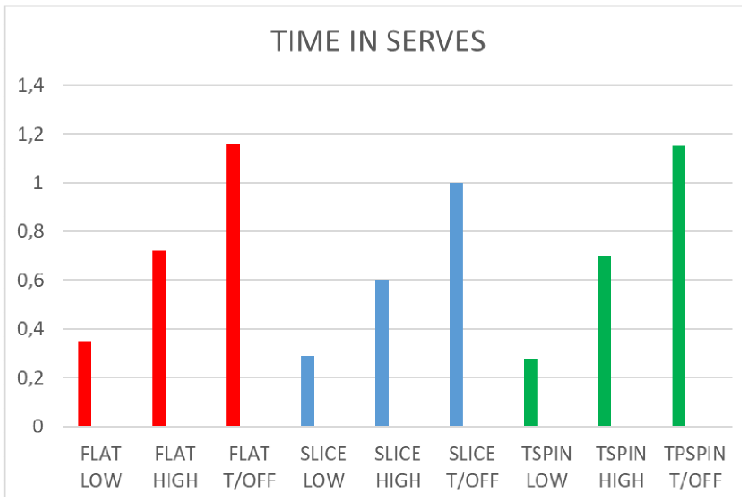

Fig. 2: Execution time of the three serves at the three times of the jump.

Discussion

The results of our study showed that during the execution of the three main types of serve, flat, slice, and topspin by young athletes aged 12 to 16 years, the maximum forces were noted at the time of the start of the upswing. From a coaching point of view, the results showed that the athletes performed with correct technique, which helps the athletes to have significant and correct "leg drive" to reach higher at the point of contact with the ball but also to execute their swing at a faster speed (Elliot & Wood, 1983). Also, the vertical force fz was greater at all times of the jump in all three serves. At the start of the upswing, the flat serve had a value of 354N, the slice serve was 370N, and the topspin service was 386N.

This means that young tennis athletes performing a successful topspin serve will have to transfer greater forces to the racket during the loading stage, a result achieved by increasing the speed of leg extension by releasing and transferring the stored energy. This, of course, is due to the coordination but also to the correct point in time at which the charging phase takes place during the execution of the three types of serves.

For the first time in the literature from our study, it appears that the young athletes who performed the three basic serves, flat, slice, and topspin presented the highest values of application of the vertical force fz during the take-off phase and specifically the flat serve with a value of 1117 N, the slice service with a value of 1083 N, and the topspin service with a value of 1171 N. This means that in learning the technique of topspin service, young tennis athletes, to transfer greater forces from the ground up to the point of contact, should exert greater pressures in the loading phase.

The duration of execution of the three basic types of serves differed in all three phases of execution of each serve. Specifically, the start time of the upswing was earlier on the topspin serve at 0.28s, then on the slice serve at 0.29s, and then on the flat serve at 0.35s. For the first time, research has shown that young tennis athletes, during the upswing phase of the serve, take different times to execute the three different types of serves. The explanation is that because the flat serve is performed like a first serve, it means it is stronger and faster. Therefore, it takes more time to store energy, which will then help in the next phase, the initiation of takeoff, to transfer greater forces upwards. The takeoff start time was on the slice serve at 0.60s, then on the topspin serve at 0.70s, and longer on the flat serve at 0.72s. Therefore, it is observed that young tennis athletes, during the take-off initiation phase, need different times to perform the three different types of serves. Finally, the use of scaffolding was a work limitation.

Conclusions

The results of our study showed that during the execution of the three main types of serve, flat, slice, and topspin by young athletes aged 12 to 16 years, the maximum forces are developed at the time of the start of the upswing. Therefore, comparing the three serves of the young athletes, in the loading stage, the forces exerted are greater first in the topspin serve, then in the slice serve, and finally in the flat serve. Of course, from the present research, it appears that the young athletes who performed the three basic serves presented the highest values of application of the vertical force fz during the take-off phase.

It has also been researched that young athletes during the upswing phase of the serve took different times to execute the three different types of serves, and the times during the initiation phase of the takeoff differed.

This study adds to the body of knowledge for coaches, who should carefully consider the variations in forces used in the three types of serves as well as the variations in execution times. By working with Biomechanics, they can use specific training strategies to help young tennis players improve their technique.

Conflicts of interest

Authors declare no conflict of interest or any disclosure of professional relationships with companies or manufacturers who will benefit from the results of the present study.

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