INTERNATIONAL JOURNAL of
IJSETS
SPORT, EXERCISE & TRAINING SCIENCES

e-ISSN 2149-8229 **Volume** 10, **Issue** 2, 98–109, (2024) ***Original Article***

https://dergipark.org.tr/tr/pub/useeabd

The Impact of Differential Learning and Functional Strength Training on Biomechanical Performance Parameters in Tennis Athletes*

Ozan ÖZDEMİR[1], Asiye Filiz ÇAMLIGÜNEY[2], Niyazi Güven ERDİL[3]

Abstract

Aim: The study aimed to investigate the effects of tennis athletes engaging in differential learning and functional strength training, alongside their routine tennis training, for 8 weeks on performance parameters in tennis, including serve speed, serve accuracy, serve depth, racquet path, and racquet speed, by interpreting it from a biomechanical perspective.

Methods: A total of 45 tennis athletes from the Turkish Interuniversity Tennis League were divided into three separate groups: the differential learning group (age: 20.7 ± 1.4 years; height: 171.4 ± 6.4 cm), the functional strength training group (age: 20.3 ± 0.9 years; height: 169.6 ± 4.3 cm), and the control group (age: 20.1 ± 1.3 years; height: 169.2 ± 4.5 cm). The functional strength training group engaged in modified biceps push-ups, modified triceps push-ups, and shoulder raise exercises, whilst the differential learning group participated in tennis serve modeling using soft materials, racquet throwing, and serving practice involving various distances and styles, alongside their functional training regimen. Before and after these training programs, which were conducted twice a week before routine tennis training for a duration of 8 weeks, biomechanical assessments and serve measurements were taken.

Results: There was a significant improvement favoring the differential learning group in the racquet side path, racquet behind head velocity, racquet side head velocity, total racquet head velocity, racquet behind path, total racquet path compared to the functional strength training group and the control group ($p < 0.05$).

Conclusion: When combined with functional strength training, differential learning seems to enhance the biomechanical parameters among tennis athletes compared to those who only undergo functional strength training.

Keywords
Differential Learning,
Functional Strength Training,
Tennis,
Biomechanics.

Article Info
Received: 26.01.2024
Accepted: 07.05.2024
Online Published: 15.06.2024

DOI:10.18826/useeabd.1414267

Tenis Sporunda Uygulanan Farklılıkla Öğrenme ve Fonksiyonel Kuvvet Antrenmanlarının Biyomekaniksel Perspektif Açısından Performans Parametreleri Üzerine Etkisi

Özet

Amaç: Tenis sporcularının 8 hafta süresince rutin tenis antrenmanlarına ek olarak farklılıkla öğrenme ve fonksiyonel kuvvet antrenmanı yapmalarının teniste performans parametrelerinden servis hızı, servis isabeti, servis derinliği, raket yolu ve raket hızına etkisini biyomekanik perspektiften araştırmak amaçlanmaktadır.

Yöntem: Çalışmaya Türkiye Üniversitelerarası Tenis Ligi oyuncusu olan 45 tenis sporcusu farklılıkla öğrenme antrenman grubu (yaş: 20,69 ± 1,44 yıl; boy: 171,35 ± 6,39 cm), fonksiyonel kuvvet antrenman grubu (yaş: 20,31 ± 0,91 yıl; boy: 169,62 ± 4,30 cm) ve kontrol grubu (yaş: 20,08 ± 1,26 yıl; boy: 169,16 ± 4,47 cm) olarak katılmıştır. Fonksiyonel kuvvet antrenman grubu modifiye biceps şınavı, modifiye triceps şınavı ve shoulder rise egzersizlerini yapmıştır. Farklılıkla öğrenme antrenman grubuna fonksiyonel kuvvet antrenmanlarına ek olarak yumuşak materyal ile tenis servisi modellemesi, raket fırlatma ve farklı mesafelerden servis çalışması uygulanmıştır. 8 hafta boyunca rutin tenis antrenmanları öncesinde haftada 2 kez uygulanmış olan bu antrenman programlarının öncesi ve sonrasında sporculara biyomekanik ve servis ölçümleri yapılmıştır.

Bulgular: Farklılıkla öğrenme antrenman grubu, kontrol grubu ve fonksiyonel kuvvet antrenman grubunun arkadan raket yolu, yandan raket yolu, toplam raket yolu, arkadan raket kafası hızı, yandan raket kafası hızı, toplam raket kafası hızı gelişim farkı yüzdesi değerleri arasında farklılıkla öğrenme grubunun lehine pozitif olarak istatistiksel olarak anlamlı fark bulunmuştur ($p<0,05$).

Sonuç: Farklılıkla öğrenme antrenmanları fonksiyonel kuvvet antrenmanları ile uygulandığında sadece fonksiyonel kuvvet antrenmanı uygulayan gruba göre tenis sporcularının biyomekanik parametrelerinde daha fazla gelişim sağlamaktadır.

Anahtar Kelimeler
Farklılıkla Öğrenme,
Fonksiyonel Kuvvet
Antrenmanları,
Tenis,
Biyomekanik.

Yayın Bilgisi
Gönderi Tarihi: 26.01.2024
Kabul Tarihi: 07.05.2024
Online Yayın Tarihi: 15.06.2024

DOI:10.18826/useeabd.1414267

---

[1] **Corresponsible Author:** Istanbul Rumeli University Faculty of Sports Science, ozanboun@hotmail.com
[2] Marmara University, Faculty of Sports Science, filizcamliguney@marmara.edu.tr
[3] Marmara Üniversitesi, guven.erdil@marmara.edu.tr
* Produced from the first author's doctoral thesis.

INTRODUCTION

Tennis is characterized as a complex sport requiring many performance parameters that necessitate consistent and high-level demonstration during competition. In tennis, mastering sport-specific technical skills is crucial, with physical performance factors also playing a significant role in achieving peak performance (Fernandez-Fernandez et al., 2014). Tennis involves various types of strokes, including volley, ground stroke, spike, and serve, which are utilized at different times and frequencies throughout the competition (Kermen, 2002). Of these parameters, the tennis serve, which is the first hit at the beginning of the point, is of particular importance.

When analyzing tennis service parameters, speed, depth, and accuracy emerge as the three most crucial factors. The speed of the serve poses challenges for the opposing player, while the depth aims to maximize the distance for their response. Additionally, accuracy refers to the server's ability to precisely hit the designated area required to initiate the point. Research has shown that the average serve speed of adult male tennis athletes, who train an average of 13.1 ± 3.8 hours per week, is 189.9 ± 15.3 km/h. (Hayes et al., 2021). Meffert et al. also reported that the first serve hit rate averaged at 64 ± 7 for both male and female players across 28,843 distinct points, derived from 124 matches during the 2016 Wimbledon tournament, as per IBM data (Meffert et al., 2018). However, all of data comes from professional level players and they do not focus on recreatioanal level such as university tennis players. In addition, the development of strength, power, coordination, and balance components is considered pivotal for achieving an effective tennis serve. For instance, it was reported that the torque produced during elbow extension significantly affected serve speeds, as evidenced by force measurements of the upper extremity (Cohen et al., 1994). Therefore, training programs aimed at improving the upper extremity are likely to enhance service parameters. Indeed, Behringer and colleagues showed that an 8-week plyometric exercise program improved serve speed (Behringer et al., 2013). In this growing body of literature, studies on static and dynamic stretching have also shown that dynamic exercises are more effective in enhancing tennis serve speed and accuracy values compared to static exercises (Gelen et al., 2012). However, attempting to develop a shot that demands such versatile skills using traditional methods, which focus on each component separately, incurs increased costs in terms of both time and energy and differential learning training is essential at this point.

Differential learning (DL) approaches are a model that aims to take learning beyond the usual model, with the specific goal of enhancing multifaceted development rapidly by surpassing familiar patterns in training. This phenomenon is also characterized as the learning of motor skills that lead to more enduring performance and quicker responses to various situations, as well as to be subconsciously ready for changing environmental conditions and to adapt at the earliest time (Erdil, 2016). DL similarly emphasizes improvement by encompassing the entire movement rather than advancing specific elements incrementally within a branch. When developing complex movements such as a tennis serve, DL doesn't divide it into smaller parts. Instead, it identifies focal points and facilitates development by integrating the tennis serve with other movements. In the tennis serve, the racket's downward movement after contacting the ball facilitates landing it in the designated service area. In DL, the racket is positioned upward, serving the ball over the service line rather than the end line, to direct it downward with the wrist's extension. In this way, tennis player must angle the racket head more downward to serve accurately to ensure that the flow of movement required for the tennis serve remains uninterrupted, allowing for efficient execution of the planned focus on the *"racquet head dropping"* technique. In particular, training methods such as serving from an elevated platform, rather than from the standard height, offer greater efficacy for players encountering difficulties in clearing the net. Moreover, this approach enables uninterrupted practice of the tennis serve flow (Hernandez-Davo et al., 2014). However, there is a gap in literature to research the effects of DL on biomechanical parameters of tennis serve. The sudies merely focus on the biomechanical parameter such as racket pat hor head speed. In addition, sample evidence suggests that DL provides longer-term development compared to classical training. While both classical training and DL resulted in similar improvements, subsequent post-test results revealed that classical training returned to initial levels shortly thereafter, whereas DL maintained its performance levels close to those achieved at the end of the intervention (Hegen et al., 2016). Most likely, this is attributed to the enhanced activation of the brain and learning processes by DL, resulting in longer-lasting effects. Güven Erdil characterizes this as the learning of motor skills that offers various performance benefits, including achieving sustained performance, reacting rapidly to situations, maintaining subconscious readiness for changing environmental conditions, and adapting promptly

(Erdil, 2016). There is also no enough study on serve parameters of recreational tennis players which trains by DL.

Functional Strength Training (FST) aims to develop strength through dynamic movement patterns, highlighting full-body engagement rather than isolated muscle groups. Furthermore, FST is known to enhance proficiency in specific functional movements within targeted domains rather than focusing solely on maximal strength gains. In support of this, while movement-specific plyometric studies reported an increase in tennis serve speed, traditional resistance exercises did not yield significant improvements (Behringer et al., 2013). Moreover, the specificity of training programs designed to the particular sport branch is a crucial factor that greatly enhances development efficiency by focusing on targeted movements. For instance, serve speed was reported to improve following tennis-specific strength and power training in semi-professional tennis players (Williams, 2020). When studies are not specifically considered for tennis, the achieved efficiency was reported to be notably low. However, following a training intervention utilizing elastic bands and light weights, tennis players experienced a 6% increase in maximum speed values and a 7.9% increase in average speed values (Treiber et al., 1998). In the study, even the control groups showed small increases, ranging from 1.8% to 2.3%. However, these gains remain relatively low when compared to the development needs of modern players. Therefore, considering the demand for athletes to achieve high efficiency in a short period, DL and FST appear to be preferred interventions over traditional training models, as they can offer efficiency across multiple components. Subsequently, this study aimed to determine the rapid development of high-level athletes' performance in tennis after DL and FST interventions.

The DL approach, which represents a deliberate and radical shift in movement patterns, offers the chance to engage in multidisciplinary work, conserving time and energy by concurrently developing numerous motor skills. Differential learning methods aim to save time and energy by expediting the individual's learning and acquisition process, particularly in multi-component skills such as the tennis serve, through a focus on 'efficient' learning tailored to each specific goal. Tennis, characterized by its demanding skill requirements and prolonged specialization process, necessitates innovative learning methodologies. Numerous distinct learning approaches are being developed for specific sports disciplines. The number of variations to which this method can be applied is almost unlimited. This study aimed to examine the impact of DL combined with FST on performance parameters in tennis athletes.

METHOD

Model of the research

The study's design comprised experimental research with three distinct groups that included a control group, a pre-test group, and a post-test group (Karasar, 2007).

Study group of the research

The study's sample size was calculated using the G Power 3.1.9.4 analysis software, with an assumed effect size of d = 0.8 and an alpha error level of 0.05, indicating that 28 participants were required. Therefore, a total of 45 participants were recruited, with 15 participants assigned to each group. Given the non-parametric distribution exhibited by the participants, analysis utilizing the Wilcoxon-Mann-Whitney test from the t-test family was conducted. The participant group involved 45 licensed athletes who voluntarily participated in the Interuniversity Tennis League, organized by the Turkish Universities Federation. The participants were divided into groups using a table of random numbers. Each participant was assigned a number ranging from 1 to 45, and subsequently, individuals were allocated to their respective groups based on the generated random numbers. The first group was designated as the "learning with difference" group, the second group as the "functional strength" group, and the third group as the control group. Following the group assignments, 15 athletes were allocated to each group, and the training programs were planned accordingly.

Participants were provided with comprehensive information about the study and informed of their right to withdraw at any time in accordance with the Helsinki protocol. The participants were divided into three separate groups: the DL group (age: 20.69 ± 1.44 years, height: 171.35 ± 6.39 cm, body weight: 63.56 ± 10.86 kg, BMI: 21.64 ± 2.68 kg/m2), the FST group (age: 20.31 ± 0.91 years, height: 169.62 ± 4.30 cm, body weight: 66.10 ± 4.54 kg, BMI: 22. 98 ± 1.46 kg/m^2), and the control group (age: 20.08 ± 1.26 years, height: 169.16 ± 4.47 cm, body weight: 63.81 ± 3.28 kg, BMI: 22.30 ± 0.56 kg/m^2).

Data collection tools of the research

In our study, both pre- and post-tests were administered, and the training programs were fully conducted in person under the guidance of a trainer. Pretest measurements were conducted in November 2022, while the final measurements were taken in January 2023 after the completion of the 8-week training regimen. All measurements were conducted on the tennis courts under room temperature conditions, between 9:00 and 11:00 in the morning. Participants were adequately rested and had been provided with nourishment prior to the measurements.

Standard dynamic tennis warm-up protocols were applied in before measurements. The warm-up program consisted of 5-8 minutes of general mobility and dynamic exercises, followed by approximately 5 minutes of shoulder exercises. Subsequently, tennis-specific exercises, including a tennis serve warm-up, were incorporated, as outlined in Fernandez-Fernandez's (2014) protocol.

The following measurements were taken in the study.

Height and Weight Measurements: Height measurements were conducted using a stadiometer (Secca 213) with a sensitivity range of ±0.1 mm, administered by the same researcher. Measurements were taken in the early morning hours, with participants barefoot and wearing minimal clothing to ensure accuracy.

Biomechanical Measurements: Racquet head speed measurements, Racquet head path measurements. Two separate videos were recorded of the participants during their serve: one from behind and another from the right. Images extracted from these videos were then uploaded to Kinovea 0.9.5 Video Analysis Program. In the video analysis program, the distance covered by the racket was computed along two distinct axes. The distance calculated along two separate axes provided the actual distance covered in the 3-dimensional plane, as determined the Pythagorean relation. The calculated distance and calculated time provided the Racket distance and speed in accordance with the laws of Newtonian motion (Serway et al., 2018). Given that all participants were right-dominant players, the service was recorded from the right side to ensure that the body did not obstruct the view of the racket's path during the serve.

Tennis Service Performance Measurements: Serve accuracy measurements, serve depth measurements, and service speed measurements.

To assess the participants' serve speed, the initial measuring officer was stationed with a radar positioned diagonally behind the participant's right side, aligning with the direction of the tennis ball's movement. The radar's trigger was activated from the moment the participant's racket made contact with the ball and was held down for an adequate duration. The numerical value displayed on the electronic screen was verbally announced and recorded by the observer. A total of 24 service speed measurements were conducted for each participant.

To ascertain whether the participant's serve reached the designated area, a second measuring officer was positioned on the left side of the court, adjacent to the serving side and aligned parallel to the service line. Throughout each service, the observer monitored whether the serve successfully landed within the designated areas. Specifically, the observer noted whether the serve hit the intended target or the appropriate area. Services failing to hit these designated zones were marked as "Aut." A total of 24 serve accuracy measurements were conducted for each participant.

To evaluate whether the participant's serves hit the power field, a third measuring officer was placed on the left side of the court, on the serving side, and next to the end line of the tennis court. During each serve, the observer monitored whether the ball landed within the power zone. For serves that successfully reached the power area, the term 'Double' was announced loudly. A total of 24 serve depth measurements were recorded for each participant.

Following the pre-test measurements, an 8-week training program began, incorporating standard dynamic tennis warm-up protocols. These protocols consisted of 5-8 minutes of general mobility and dynamic exercises, followed by approximately 5 minutes of shoulder exercises. Subsequently, tennis-specific exercises, including a tennis serve warm-up, were integrated into the training regimen (Fernandez-Fernandez 2014). After the completion of the 8-week training periods, post-tests were administered in an identical manner to the pre-tests. Before conducting the post-test measurements, the same warm-up protocol was applied, and identical measurements were conducted for all study groups.

Data analysis of the research

The collected data were analyzed using the SPSS (Statistical Package for Social Sciences), Windows version 22.0 program. Descriptive statistics including counts, minimum and maximum values, means, and standard deviations were calculated. Normality tests were conducted using Q-Q plot analyses, histograms, and Shapiro-Wilk values. Outlier values were retained in the dataset, and non-parametric tests were utilized for datasets that did not exhibit a normal distribution. For intra-group pre- and post-test comparisons, paired t-test was applied for normally distributed values, and the Wilcoxon sequential signs test was used for non-normally distributed values. In normally distributed groups, one-way ANOVA analysis was conducted to assess the significance levels of the first and last test data across the groups. Post-hoc analysis using Games-Howell method was employed for intergroup analysis. For groups that did not exhibit normal distribution, Kruskal-Wallis analysis was applied, followed by pairwise post-hoc analysis.

For comparisons between groups, the development difference percentages were calculated using the following formula:

% Development Difference = [Last value - Initial value] / Initial value x 100 was applied (Silva, 2019).

Subsequently, one-way ANOVA analysis was conducted for the percent development difference groups showing normal distribution. Games-Howell post-hoc analysis was used for intergroup analysis in normally distributed datasets. For groups that did not display normal distribution, Kruskal-Wallis analysis was applied, followed by pairwise post-hoc analysis.

FINDINGS

The findings obtained as a result of the research are presented in the following tables.

Table 1. Demographic characteristics of differential learning and functional strength groups

Age and Height		n	Min	Max	Mean	SD
Differential learning	Height (cm)	15	150	188	171.35	6.39
	Age (y)	15	19	23	20.69	1.44
Functional strength training	Height (cm)	15	157	177	169.62	4.30
	Age (y)	15	18	22	20.31	0.96
Control	Height (cm)	15	167	174	169.16	4.47
	Age (y)	15	18	22	20.08	1.26

SD: Standard deviation

Various descriptive results are detailed in the table (Table 1).

Table 2. Pre- and post-test results of biomechanical parameters of the differential learning group

	Biomechanical parameters	n	Min	Max	Mean	SD	p
Distance	Pre-racquet behind path (m)	15	18.36	34.30	27.96	4.37	.009
	Post-racquet behind path (m)	15	21.45	35.42	29.72	4.22	
	Pre-racquet side path (m)	15	8.55	16.26	13.05	1.97	<.001
	Post-racquet side path (m)	15	9.58	20.18	15.34	2.65	
	Pre-total racquet path (m)	15	28.12	39.75	30.95	4.07	<.001
	Post-total racquet path (m)	15	30.42	41.98	33.56	4.10	
Velocity	Pre-racquet behind head velocity (m/s)	15	41.66	52.67	46.68	7.42	<.001
	Post-racquet behind head velocity (m/s)	15	42.12	55.76	49.25	8.06	
	Pre-racquet side head velocity (m/s)	15	19.12	24.56	20.38	3.84	<.001
	Post-racquet side head velocity (m/s)	15	18.12	25.67	23.31	3.84	
	Pre-total racquet head velocity (km/h)	15	172.56	199.56	183.65	27.96	<.001
	Post-total racquet head velocity (km/h)	15	178.56	221.87	196.41	29.89	

$p<0.05$; Independent Samples t Test, SD: Standard deviation

There was a significant difference between pre- and post-test in biomechanical parameters of the DL group (Table 2) ($p<0.05$).

Table 3. Pre- and post-test results of biomechanical parameters of the functional strength training group

Biomechanical parameters		n	Min	Max	Mean	SD	p
Distance	Pre-racquet behind path (m)	15	23.45	32.16	28.34	2.12	.946
	Post-racquet behind path (m)	15	24.12	35.23	27.61	4.22	
	Pre-racquet side path (m)	15	11.22	17.05	15.65	2.66	<.001
	Post-racquet side path (m)	15	12.24	19.23	15.18	2.47	
	Pre-total racquet path (m)	15	27.12	35.75	32.49	1.74	<.001
	Post-total racquet path (m)	15	30.42	37.98	31.69	3.40	
Velocity	Pre-racquet behind head velocity (m/s)	15	47.46	58.64	51.12	4.09	<.001
	Post-racquet behind head velocity (m/s)	15	44.02	56.79	50.75	4.17	
	Pre-racquet side head velocity (m/s)	15	19.08	27.53	22.75	3.58	<.001
	Post-racquet side head velocity (m/s)	15	16.15	24.63	22.54	2.10	
	Pre-total racquet head velocity (km/h)	15	162.53	212.46	201.70	16.19	<.001
	Post-total racquet head velocity (km/h)	15	179.56	231.27	200.19	12.94	

$p<0.05$; Independent Samples t Test, SD: Standard deviation

No significant difference was noted in biomechanical parameters in the FST group (Table 3) ($p>0.05$).

Table 4. Pre- and post-test results of biomechanical parameters of the control group

Biomechanical parameters		n	Min	Max	Mean	SD	p
Distance	Pre-racquet behind path (m)	15	23.74	38.86	30.34	4.26	.623
	Post-racquet behind path (m)	15	21.15	40.12	30.57	4.37	
	Pre-racquet side path (m)	15	11.63	18.07	14.44	1.62	.337
	Post-racquet side path (m)	15	10.69	18.12	14.26	1.63	
	Pre-total racquet path (m)	15	28.49	41.95	33.70	3.76	.746
	Post-total racquet path (m)	15	26.37	43.12	33.84	3.82	
Velocity	Pre-racquet behind head velocity (m/s)	15	40.15	65.21	49.57	6.56	.907
	Post-racquet behind head velocity (m/s)	15	38.72	63.16	49.63	6.51	
	Pre-racquet side head velocity (m/s)	15	19.72	29.34	22.77	3.26	.889
	Post-racquet side head velocity (m/s)	15	18.12	25.67	23.82	3.56	
	Pre-total racquet head velocity (km/h)	15	172.56	199.56	196.77	23.27	.343
	Post-total racquet head velocity (km/h)	15	156.72	246.75	198.63	23.16	

$p<0.05$; Independent Samples t Test, SD: Standard deviation

No significant difference was noted in biomechanical parameters in the Control group (Table 4) ($p>0.05$).

Table 5. Pre- and post-test results of service parameters of the differential learning group

Serve parameters	n	Min	Max	Mean	SD	p
Pre-target area hit	15	0	13	5.08	3.38	.288
Post-target area hit	15	2	13	6.08	3.33	
Pre-other area hit	15	0	5	2.54	1.51	.337
Post-other area hit	15	1	5	2.54	1.51	
Pre-total hit	15	0	13	7.92	3.45	.654
Post-total hit	15	3	14	8.08	3.28	
Pre-out	15	7	20	16.08	4.09	.885
Post-out	15	24	21	15.92	3.28	
Pre-average velocity (m/s)	15	42.12	109	89.02	14.92	.858
Post-average velocity (m/s)	15	51.78	130	90.09	23.52	
Pre-accurate serve average velocity (m/s)	15	72.54	155	78.54	29.54	.299
Post-accurate serve average velocity (m/s)	15	68.32	122	87.60	23.52	
Pre-Out Serve Average Velocity (m/s)	15	67.88	123.7	90.08	21.62	.804
Post-Out Serve Average Velocity (m/s)	15	46.67	120.5	91.52	24.12	

$p<0.05$; Independent Samples t Test, SD: Standard deviation

Significant improvements in service parameters were observed in the DL group (Table 5) ($p < 0.05$).

Table 6. Pre- and post-test results of service parameters of the functional strength training group

Serve parameters	n	Min	Max	Mean	SD	p
Pre-target area hit	15	1	6	4.62	2.36	.877
Post-target area hit	15	2	7	4.69	1.80	
Pre-other area hit	15	3	8	3.85	1.46	.240
Post-other area hit	15	4	11	3.46	1.76	
Pre-total hit	15	4	7	8.46	1.56	.527
Post-total hit	15	7	12	8.15	1.63	
Pre-out	15	8	15	15.54	1.56	.527
Post-out	15	9	12	15.85	1.63	
Pre-average velocity (m/s)	15	42.54	109.22	99.34	19.99	.152
Post-average velocity (m/s)	15	51.12	130.43	98.40	19.45	
Pre-accurate serve average velocity (m/s)	15	72.45	155.68	102.41	23.82	.990
Post-accurate serve average velocity (m/s)	15	68.63	122.25	102.39	22.03	
Pre-out serve average velocity (m/s)	15	39.50	99.12	88.55	3.19	.395
Post-out serve average velocity (m/s)	15	46.12	102.54	88.04	3.06	

p<0.05; Independent Samples t Test, SD: Standard deviation

No significant changes in service parameters were noted in the FST (Table 6) (p > 0.05).

Table 7. Pre- and post-test results of service parameters of the control group

Serve parameters	n	Min	Max	Mean	SD	p
Pre-target area hit	15	0	13	5.62	3.71	.717
Post-target area hit	15	1	14	5.85	3.34	
Pre-other area hit	15	0	5	2.15	1.68	.247
Post-other area hit	15	0	5	2.92	1.71	
Pre-total hit	15	2	13	7.77	4.15	.144
Post-total hit	15	5	14	8.77	2.55	
Pre-out	15	9	19	16.23	4.5	.146
Post-out	15	10	19	15.31	2.59	
Pre-average velocity (m/s)	15	59.07	126.91	92.64	17.53	.408
Post-average velocity (m/s)	15	60.9	124.67	92.09	16.39	
Pre-accurate serve average velocity (m/s)	15	52	125.4	91.93	19.45	.764
Post-accurate serve average velocity (m/s)	15	53.56	125.78	91.73	18.85	
Pre-out serve average velocity (m/s)	15	65.33	129.30	93.26	18.79	.528
Post-out serve average velocity (m/s)	15	74.10	130.56	92.95	19.70	

p<0.05; Independent Samples t Test, SD: Standard deviation

No significant changes in service parameters were noted in the Control group (Table 7) (p > 0.05).

Table 8. Developmental differences between groups with parametric distribution

Biomechanical Parameters			CG	FST	DL
Control	Racquet side path (m)	Mean Difference	—	16.7	19.57
		p-value	—	<.001	< .001
	Racquet behind head velocity (m/s)	Mean Difference	—	5.31	6.187
		p-value	—	0.004	< .001
	Racquet side head velocity (m/s)	Mean Difference	—	10.9	14.28
		p-value	—	0.039	0.087
	Total racquet head velocity (km/h)	Mean Difference	—	6.00	7.60
		p-value	—	< .001	< .001
Functional strength training	Racquet side path (m)	Mean Difference		—	2.83
		p-value		—	0.606
	Racquet behind head velocity (m/s)	Mean Difference		—	0.878
		p-value		—	0.818
	Racquet side head velocity (m/s)	Mean Difference		—	3.39
		p-value		—	0.847
	Total racquet head velocity (km/h)	Mean Difference		—	1.59
		p-value		—	0.490
Differential learning	Racquet side path (m)	Mean Difference			—
		p-value			—
	Racquet behind head velocity (m/s)	Mean Difference			—
		p-value			—
	Racquet side head velocity (m/s)	Mean Difference			—
		p-value			—
	Total racquet head velocity (km/h)	Mean Difference			—
		p-value			—

*One-way ANOVA, Games- Howell Post-hoc analysis

There was a significant improvement favoring the differential learning group in the Racquet side path, Racquet behind head velocity, Racquet side head velocity (m/s), and Total racquet head velocity compared to the functional strength training group and the control group (Table 8). ($p < 0.05$).

Table 9. Developmental differences between groups with non-parametric distribution

Biomechanical Parameters			**CG**	**FST**	**DL**
Control	Racquet behind path (m)	w	—	-3.082	0.075
		p-value	—	-3.445	0.039
	Total racquet path (m)	w	—	-4.678	-5.040
		p-value	—	0.003	0.001
Functional strength training	Racquet behind path (m)	w		—	-0.544
		p-value		—	0.922
	Total racquet path (m)	w		—	0.761
		p-value		—	0.853
Differential learning	Racquet behind path (m)	w			—
		p-value			—
	Total racquet path (m)	w			—
		p-value			—

* Kruskal-Wallis, Pairwise Post-hoc analysis

There was a significant improvement favoring the differential learning group in the Racquet behind path and Total racquet path compared to the functional strength training group and the control group (Table 9).

DISCUSSION

There are many different DL trainings to improve skills in sports. DL has more positive effects on the hitting quality of football players than classical approaches (Oftadeh et al., 2022). For example, It is known that practicing techniques during a game, such as hitting the football with one arm raised or attempting to maintain a position with one eye closed, can have positive effects on athletes' adaptability (Erdil, 2016). Especially DL and training in diverse pressure environments are known to improve the adaptation abilities of athletes. A crucial aspect of this training lies in focusing on footwork as the primary starting point. Instead of depending solely on conventional footwork techniques, tennis players can elevate their footwork by incorporating methods like jump-sprint-step laddering, resulting in significant enhancements in performance (Benko et al., 2007).

Tennis is a sport which play in diverse pressure environments and it demands a good footwork from players. Within these instructional models, various verbal communication techniques are employed to help athletes practice specific movement patterns. For instance, rather than instructing to 'move your racket downwards and then upwards,' coaches might say, 'try reversing your racket motion from 9 o'clock to 3 o'clock.' Similarly, instead of simply saying 'bend your waist backward,' coaches might encourage athletes with, 'imagine you're lifting a prize and assume that posture,' making the movement easier to visualize and practice (Meier et al., 2020). In a study focused on speed enhancement, the differential learning group engaged in exercises like serving from positions 1 meter inside or 1 meter outside the service line, resulting in a higher increase in service speed compared to the classical study group (Hernandez-Davo et al., 2014). Our study aligns with prior research examining tennis serves from various positions and racket throws. Also the study contains DL trainings that have visual and verbal trainings and these kind of trainings improve the results of players and the results are similar with previous studies in literature.

Considering that DL involves a wide array of training methodologies, it is important to design the training to be both suitable and effective. For instance, in a study examining the transferability of gains from one foot to the other bilaterally among football players, DL techniques were applied to the non-dominant feet. However, no significant difference was observed in pre- and post-training values for the dominant foot (Şener, 2018). Similarly, our study revealed that there was no significant difference in the service accuracy values of the players before and after the DL training. DL is also recognized to impact participants' attention spans. Choosing the right DL training method to improve skills is very important. Indeed, a previous research has identified significant differences between pre-test and post-test data on attention spans following the application of DL to the participants (Topsakal, 2019), supporting our findings showing the application of service modeling training with soft material and DL group resulted in positive improvements in service parameters. Also, in a study conducted on handball athletes, significant improvements were noted in participants' agility, t-test, and obstacle test scores following DL (Çakıt et al., 2022). Given that the tennis serve demands both dynamic and static balance, our study evaluated the positive effects of DL on serve parameters. Tennis serve also needs high level of agility and DL trainings are effect it positively.

Tennis serve is a kinetic chain movement that requires technique and coordination as well as involves the whole body (Williams, 2020). The FST is important for high coordination level and The FST applied in our study also provided improvements in the hitting performances of the athletes because many muscle groups come into play during the tennis serve. According to previous research, there is a significant relationship between isokinetic trunk rotation and functional medicine ball exercises (Ellenbecker et al., 2004). The fact that the biceps and triceps muscles work in an agonist-antagonist relationship during the serving flow underscores the high coordination demands on these muscle groups. Our study contains biceps and triceps push-up tainings and they improve the functional strength. In another study, concentric and eccentric exercises were administered to training groups, and their outcomes were compared with those of a control group. Notably, both training groups exhibited an approximately 11% enhancement in serve speed performance. Furthermore, improvements were observed in measurements taken at 60 and 180 degrees inside and outside the shoulder (Mont et al., 1994). In our study, we also found a significant differences in deltoid muscle strength measurements between the FST group and other groups ($p < 0.05$) and the deltoid strength is highly related to the power of tennis serve. Another study has indicated that deceleration holds equal importance to acceleration in muscle movement, showing the crucial role of eccentric force development in athlete training (Kovacs et al.,, 2008). In our study, we observed a statistically significant difference between the right biceps, left biceps, right triceps, left triceps, right deltoid, and left deltoid values in the FST group, highlighting an improvement following the FST program ($p<0.05$). In addition, a significant relationship was also noted between DL and FST groups in right deltoid strength, consistent with earlier research findings. The results show that FST training is useful to improve tennis serve performances because of the effect of them on the upper-extremity muscle groups.

A study applying a protocol resembling ours investigated the alterations in serve speeds and serve accuracy. In this study, one group engaged in plyometric training twice a week for 8 weeks, while another group performed machine-based resistance exercises. After the training intervention, a higher percentage of serve speed improvement was found in the serve speeds of the group doing tennis-specific plyometric training compared to the group doing machine-based resistance training, while no difference was evident in the serve accuracy values between the groups (Behringer et al., 2013). In a study, it was found that roughly 65% of the power generated in the service originates from the shoulder, with approximately 40% attributed to internal rotation of the shoulder joint (Elliott, 2006). In our study, we observed improvements in both right and left deltoid strength values following FST. In another study by Hayes and colleagues, they compared service speeds with various measurements taken on a power platform. They reported a significant relationship between serve speed values and peak power values, counter-movement jump values, as well as internal and external shoulder rotation measurements (Hayes et al., 2021). These findings corroborate our results, demonstrating an enhancement in serve speed while observing no alteration in serve accuracy because applying FST is much more effective from the machine-based resistance training is tennis because of the real-time effect of it.

In a study, serves were performed under conditions of both eyes open and closed. The average racket speed was measured at 32.93 ± 5.67 m/s with eyes open and 28.06 ± 4.74 m/s with eyes closed. Furthermore, it was observed that the total distance covered by the racket decreased when participants performed serves with closed eyes (Giblin et al., 2017). In our study, following the learning training with a similar approach, a serve speed of 54.56 ± 8.30 m/s and an improvement percentage of 7.01% were achieved. Additionally, the average racket path increased by 2.61 meters compared to baseline measurements. In another study involving professional tennis athletes, the movement speeds of various body parts during the tennis serve were analyzed, revealing a hand speed of 47 mph (equivalent to 75.64 km/h) (Kibler, 1995). It's worth noting that in our study, we measured the speed of the racket rather than directly measuring the speed of the hand. Moreover, we calculated the average speed value throughout the entire movement. Therefore, any observed differences in speed measurements may stem from these methodological distinctions.

In another study, the lower and upper extremity strengths and serve speeds in tennis athletes were measured before and after the competition, and it was reported that the participants' internal shoulder rotation forces and average serve speeds constantly decreased (Martin et al., 2016). In our study, it is highly probable that conducting serve and strength measurements outside of a competitive environment prevented athlete burnout, consequently resulting in the absence of a consistent decrease in the specified values during the test measurements.

Furthermore, field-based studies using biomechanical analysis have reported that making small fluctuating movements in the movement planes of the hand holding the racket during the serve could reduce the speed and accuracy of the serve (Antúnez et al., 2012). In the present study, we used *the Kinovea Video Analysis Program* known for its affordability, portability, and user-friendly interface (Adnan et al., 2018). This software is both reliable and valid, offering a practical solution that can be readily utilized by coaches and recreational clubs, in contrast to more costly movement analysis systems (Delgado-Garcia et al., 2022). After our interventions, the fluctiotion of the serve reduces and gets better the serve performance. It enhances the results of some essential parameters of tennis serve; depth and speed.

CONCLUSION

Based on the data obtained in the present study, it appears that differential learning have a significant impact on the biomechanical parameters of the participants when administered alongside functional strength training.

SUGGESTIONS

Further studies are warranted to expand upon the current findings, particularly by including larger groups of participants and extending the duration of the training period. Additionally, exploring the application of these findings across different sports branches would contribute to a more comprehensive understanding.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

ACKNOWLEDGEMENT

My little monkeys, IDA and ERA…

Ethical Approval Permission Information
Ethics Committee: Clinical Research Ethics Committee of Marmara University, Faculty of Medicine
Division / Protocol No: May 31, 2022/ 09.2022.835

REFERENCES

Adnan, N. M. N., Ab Patar, M. N. A., Lee, H., Yamamoto, S. I., Jong-Young, L., & Mahmud, J. (2018). Biomechanical analysis using Kinovea for sports application. *In IOP conference series: Materials science and engineering, 342*(1), 012096.

Antúnez, R. M., Hernández, F. J. M., García, J. P. F., Vaíllo, R. R., & Arroyo, J. S. D. (2012). Relationship between motor variability, accuracy, and ball speed in the tennis serve. *Journal of Human Kinetics*, 33- 45.

Behringer, M., Neuerburg, S., Matthews, M., & Mester, J. (2013). Effects of two different resistance-training programs on mean tennis-serve velocity in adolescents. *Pediatric Exercise Science, 25*(3), 370-384.

Benko, U., & Lindinger, S. (2007). Differential coordination and speed training for tennis footwork. *Coaching and Sport Science Review, 41*, 10-11.

Cohen, D. B., Mont, M. A., Campbell, K. R., Vogelstein, B. N., & Loewy, J. W. (1994). Upper extremity physical factors affecting tennis serve velocity. *The American Journal of Sports Medicine, 22*(6), 746-750.

Çakıt, İ., Çamlıgüney, A.F., & Erdil, G. (2022). The Impact of Differential Learning Model on Motor Skills and Handball-Specific Coordination Performance in 11-13-Year-Old Beginners in Handball. *International Journal of Sport Exercise and Training Sciences, 8*(4), 152-160.

Delgado-García, G., Coll, J. S., Infantes, S. C., Malagón, E. J. R., Colio, B. B., & Fernández, F. T. G. (2022). Validation of wearables for technical analysis of tennis players. *International Journal of Racket Sports Science, 4*(2), 56-60.

Ellenbecker, T. S., & Roetert, E. P. (2004). Strength in Elite Tennis Players. *Medicine & Science in Sports & Exercise, 195*(9131/04), 1959.

Elliott, B. (2006). Biomechanics and tennis. *British Journal of Sports Medicine, 40*(5), 392-396.

Erdil, G. (2016). Farklılıkla öğrenme motor becerilerin öğrenimine farklı bir bakış. *Marmara Üniversitesi Spor Bilimleri Dergisi, 1*(1), 39-48.

Fernandez-Fernandez, J., Ulbricht, A., & Ferrauti, A. (2014). Fitness testing of tennis players: How valuable is it? *British Journal of Sports Medicine, 48*(Suppl 1), 22-31.

Gelen, E., Dede, M., Bingul, B. M., Bulgan, C., & Aydın, M. (2012). Acute effects of static stretching, dynamic exercises, and high volume upper extremity plyometric activity on tennis serve performance. *Journal of Sports Science & Medicine, 11*(4), 600.

Giblin, G., Whiteside, D., & Reid, M. (2017). Now you see, now you don't… the influence of visual occlusion on racket and ball kinematics in the tennis serve. *Sports Biomechanics, 16*(1), 23-33.

Hayes, M. J., Spits, D. R., Watts, D. G., & Kelly, V. G. (2021). Relationship between tennis serve velocity and select performance measures. *The Journal of Strength & Conditioning Research, 35*(1), 190-197.

Hegen, P., Rizzi, N., & Schöllhorn, W. I. (2016). Comparison of the differential learning approach in the form of games and traditional tennis training. *In Book of Abstract of 21st Annual Congress of the European College of Sport Science. Wien* (Vol. 459).

Karasar, N. (2007). Bilimsel araştırma yöntemi: kavramlar, ilkeler, teknikler (2). Nobel yayın dağıtım.

Kermen, O. (2002). Tenis: teknik ve taktikleri (1). Nobel yayın dağıtım.

Kibler, W. B. (1995). Biomechanical analysis of the shoulder during tennis activities. *Clinics in Sports Medicine, 14*(1), 79-85.

Kovacs, M. S., Roetert, E. P., & Ellenbecker, T. S. (2008). Efficient deceleration: The forgotten factor in tennis-specific training. *Strength & Conditioning Journal, 30*(6), 58-69.

Martin, C., Bideau, B., Delamarche, P., & Kulpa, R. (2016). Influence of a prolonged tennis match play on serve biomechanics. *PloS One, 11*(8), e0159979.

Meffert, D., O'Shannessy, C., Born, P., Grambow, R., & Vogt, T. (2018). Tennis serve performances at break points: Approaching practice patterns for coaching. *European Journal of Sport Science, 18*(8), 1151-1157.

Meier, C., Frank, C., Gröben, B., & Schack, T. (2020). Verbal instructions and motor learning: How analogy and explicit instructions influence the development of mental representations and tennis serve performance. *Frontiers in Psychology, 11*, 2.

Mont, M. A., Cohen, D. B., Campbell, K. R., Gravare, K., & Mathur, S. K. (1994) Isokinetic concentric versus eccentric training of shoulder rotators with functional evaluation of performance enhancement in elite tennis players. *The American Journal of Sports Medicine, 22*(4), 513-517.

Oftadeh, S., Bahram, A., Yaali, R., Ghadiri, F., & Schöllhorn, W. I. (2022). External Focus or Differential Learning: Is There an Additive Effect on Learning a Futsal Goal Kick? *International Journal of Environmental Research and Public Health, 19*(1), 317.

Sawczyn, M. (2020). Effects of a periodized functional strength training program (FST) on Functional Movement Screen (FMS) in physical education students. *Physical Education of Students, 24*(3), 162-167.

Serway, R. A., & Jewett, J. W. (2018). *Physics for scientists and engineers*. Cengage learning.

Şener, M. (2018) 13-15 yaş genç amatör futbolcularda farklılıkla öğrenme metodunun bilateral gelişime etkisinin incelenmesi. (Yayınlanmamış Doktora Tezi). Marmara Üniversitesi, İstanbul.

Treiber, F. A., Lott, J., Duncan, J., Slavens, G., & Davis, H. (1998). Effects of Theraband and lightweight dumbbell training on shoulder rotation torque and serve performance in college tennis players. *The American Journal of Sports Medicine*, *26*(4), 510-515.

Williams, J. A. (2020). Effect of specific strength and power training on serving velocity in tennis players. *Journal of Australian Strength & Conditioning*, *28*(5), 80-92.

CITING

Özdemir, O., Çamlıgüney, A.F. & Erbil, N.G. (2024). The Impact of Differential Learning and Functional Strength Training on Biomechanical Performance Parameters in Tennis Athletes. International Journal of Sport Exercise and Training Sciences - IJSETS, 10(2), 98-109. DOI: 10.18826/useeabd.1414267.