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Original Article

Comparison of the Foot-Ankle Characteristics and Physical and Functional Performance of Racquet Sport Players

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ABSTRACT

Objective: The aim of our study was to assess and compare foot–ankle characteristics and physical performances of different types of racquet sport players.

Methods: The study was carried out with a control group and 3 racquet sports groups. Ten individuals were included in each group. Foot static and dynamic pressure distributions were assessed with a pedobarography device (FreeMed® Maxi; Sensor Medica®; Guidonia Montecelio, Rome, Italy). Functional performance parameters were evaluated with several tests. Differences between groups were evaluated with the 1-way analysis of variance test, and the Tukey's Honestly Significant Difference Test (HSD) test was used as a post hoc test to determine the significant difference between groups.

Results: There was no significant difference regarding pedobarographic variables between groups ($P > .05$). Blind Stork Balance Test parameters were found to be different between groups and significantly higher in the tennis group than the control group ($P < .05$). Modified Star Balance Test parameters were found to be different between groups, and results in table tennis players were found to be significantly higher than in badminton group ($P < .05$).

Conclusion: As a result of this study, we could not detect any differences in pedobarographic variables in racquet sport players. Characteristic differences regarding physical performances were found in different kinds of racquet sports. There is a need for more extensive studies on this subject.

Keywords: Pedobarography, performance, racquet sport, tennis

Introduction

"Racquet sports" are games in which players use a racquet or paddle to hit a ball or other object, and this term applies for sports such as badminton, tennis, and table tennis. Racquet sports mainly require excellent abilities in balance, coordination, agility, and speed.[1] Racquet sport players stand for a long time on their lower extremities to make weight transfer from one to another and to promote their moves in various directions during the game.[2] Forward lunge and jumping movements are known as the critical moves that allow players to move as quickly as possible for the next move.[3] In addition, another important determinant for the forward lunge and athletic jump performance is the ability to move quickly with maximum power strength.[4] Further, foot and ankle assessments are important in terms of supplying essential information regarding susceptibility to injury or determining risk factors for sports. It has been reported that stress accumulates on both Achilles tendon and anterior knee tendons of athletes engaged in racquet sports after the competition; therefore, it is important to evaluate the foot–ankle characteristics and related performance parameters of the athletes.[5]

In biomechanical analyses of racquet players, trunk rotation and upper extremity movements were found to be key elements leading to optimum racquet speed and positioning at impact.[6] Lino and Kojima reported that both shoulder and trunk rotations contribute to the speed of racquet and that kinetic energy should be transferred from the trunk to upper extremity segments by a closed kinetic chain instead of an open kinetic chain path.[7] Since lower extremities are interconnected with trunk and upper extremities as a kinetic chain, the upper extremity and lower extremities should be considered as a whole in the nature of the training in racquet sports.[8] It has been demonstrated that foot and ankle characteristics such as load distribution allow different variations in coordination pattern and affect postural control and performance of athletes.[1] These parameters

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were found as factors that affect performances in sports with sudden changes such as racquet sports.[9] To supply harmonious kinematic chain in the body, kinetic and kinematic characteristics of foot–ankle characteristics are needed to be in optimum values, and parameters affecting the lower extremity performance such as balance, coordination, and muscle strength are needed to be in the normal values.[9,10]

On the other hand, functional measurements including balance, endurance, and muscle strength are critical for clinical decision-making, especially in professional athletes where competition requires complex movements involving biomechanical chain in lower extremity.[11] Muscle strength, power, agility, kinetic and kinematic parameters in lower extremity are reported as essential parameters in athletes to estimate the risk of their injury potentials.[12] In addition, performance tests that are used in specific sports aimed to measure physical performance and compare improvements in functional outcomes need to be considered.[13]

There are only a few studies aiming to investigate the risks of injury in racquet players and compare the potential differences regarding characteristics of sports.[14] In particular, it was stated that there were more potential injury body parts detected in different racquet sports.[14] For instance, body areas of foot and trunk were determined as more prone to injury in badminton players, whereas hip and ankle were specified for both table tennis and tennis players. Regarding potential differences in the risk of injury in different racquet sports, 3 different groups of racquet players were included in our study to explore foot and ankle characteristics and compare the results of groups.[15]

When the literature was examined, there were no studies examining and comparing foot–ankle characteristics and athletic performance in different types of racquet sports. The aim of our study was to compare the foot–ankle characteristics and physical performance in different types of racquet sports and reveal the superiority of the groups over each other.

Methods

Study Design

This was a cross-sectional study comparing foot–ankle and athletic performance in 3 different racquet sports. This study consisted of 4 groups: table tennis, tennis, badminton players, and a control group. All groups were informed to abstain from food, tea, coffee, and cigarettes for 3 hours before the test. Pedobarographic measurement was performed to determine foot–ankle characteristics of the participants. Y-shaped Modified Star Excursion Balance Test, Stork Balance Test, Blind Stork Balance Test, Standing Long Jump Test, Shuttle Test, and Sit-up Test were applied to evaluate functional performances. Before starting functional performance tests, athletes were warmed up with free walking at their own walking speed for 15 minutes. A 10-minute break was given between tests so that fatigue did not affect functional performance.[16] Assessments were completed by the same researcher, and it took approximately 120 minutes to complete all the procedures.

The study was carried out in accordance with the Declaration of Helsinki, and ethical approval was obtained from the Istanbul Medipol University's Non-Interventional Ethics Committee with the registration number 10840098-604.01.01-E.53502. Participants were informed about the purpose of the study and the relevant data collection forms on the consent page. Before participants were included in the study, their consent was obtained with a voluntary consent form.

Power analysis was conducted to determine the number of participants to be included in the study. The power of the test was calculated with the G*Power 3.1 program. In a similar study in the related literature, the effect size was calculated as 1.071 in the study conducted by Asadi 2015.[17] In order to exceed the value of 95% in determining the power of the study, at 5% significance level and 1.071 effect size, it is necessary to reach 40 people, including 10 people in each group ($df=9$; $t=1.833$).

Participants

CONSORT participant flow diagram was presented in Figure 1. Ten individuals for each group were included in the study at the Istanbul Medipol University University. Inclusion criteria for the study were participants who were between the ages of 18 and 25, were active players in the branches of racquet sports, and had right dominant leg. Exclusion criteria for the study were participants who had a history of surgery in the foot and ankle joint, had acute injury in foot and ankle joint, had pain during the test, used drugs that would affect the balance, had any chronic neurological disorders, and active menstrual period.[18]

Measurements

Demographic Data Form: Demographic variables such as age, height, weight, and gender were recorded. In addition, information regarding their experiences in racquet sports and training schedule in a week were obtained.

Foot–Ankle Characteristic Assessment

Pedobarographic Evaluation: It is a gait analysis method that allows the ground reaction force to be measured sensitively and pointwise while standing and walking. FreeMed® Maxi (Sensor Medica®; Guidonia Montecelio, Rome, Italy) pedobarography device was used in the study. The platform's sensors are 24-karat gold, providing high repeatability and reliability.[19] Participants were evaluated in 2 stages, statically and dynamically. Static test was performed barefoot, standing freely, with the arms resting freely along the body with feet parallel and slightly spaced apart. Participants were pressed on the pressure platform with both feet at the same level as the heels, with a distance of 5 cm between them for 10 seconds.[20] During the dynamic tests, participant was requested to walk at his/her own pace along the measurement path 12 times. Before the actual measurement began, participants were allowed to walk 5 times on the platform.[20,21] Outcomes measures were obtained as shown in Figure 2.

Functional Performance Evaluations

Modified Star Excursion Balance Test: To measure dynamic postural balance and control, each participant stood on the leg to be tested with their hands on their waists, while reaching as far as possible with the other leg in the anterior, posteromedial, and posterolateral directions (Y-shaped) and return to its original position. The furthest point in the distance that participants could reach in the specified directions was measured. The test procedure was repeated for the other side with a rest period of 10 seconds between them. Before applying the test procedure, participants were allowed to take 3 or 4 attempts. The mean value of 3 measurements was recorded in centimeters. The test was repeated if the sole of the foot was completely placed on the ground or the person rested after touching the toe.[22]

Stork Balance Test

Postural static balance was evaluated using the Stork Balance Test. In this test, the subject stood on his or her dominant leg. The participants were instructed to lift and hold the contralateral leg against the medial side of the knee of the stance leg while keeping his or her hands on the iliac crests. The trial ended when the heel of the involved

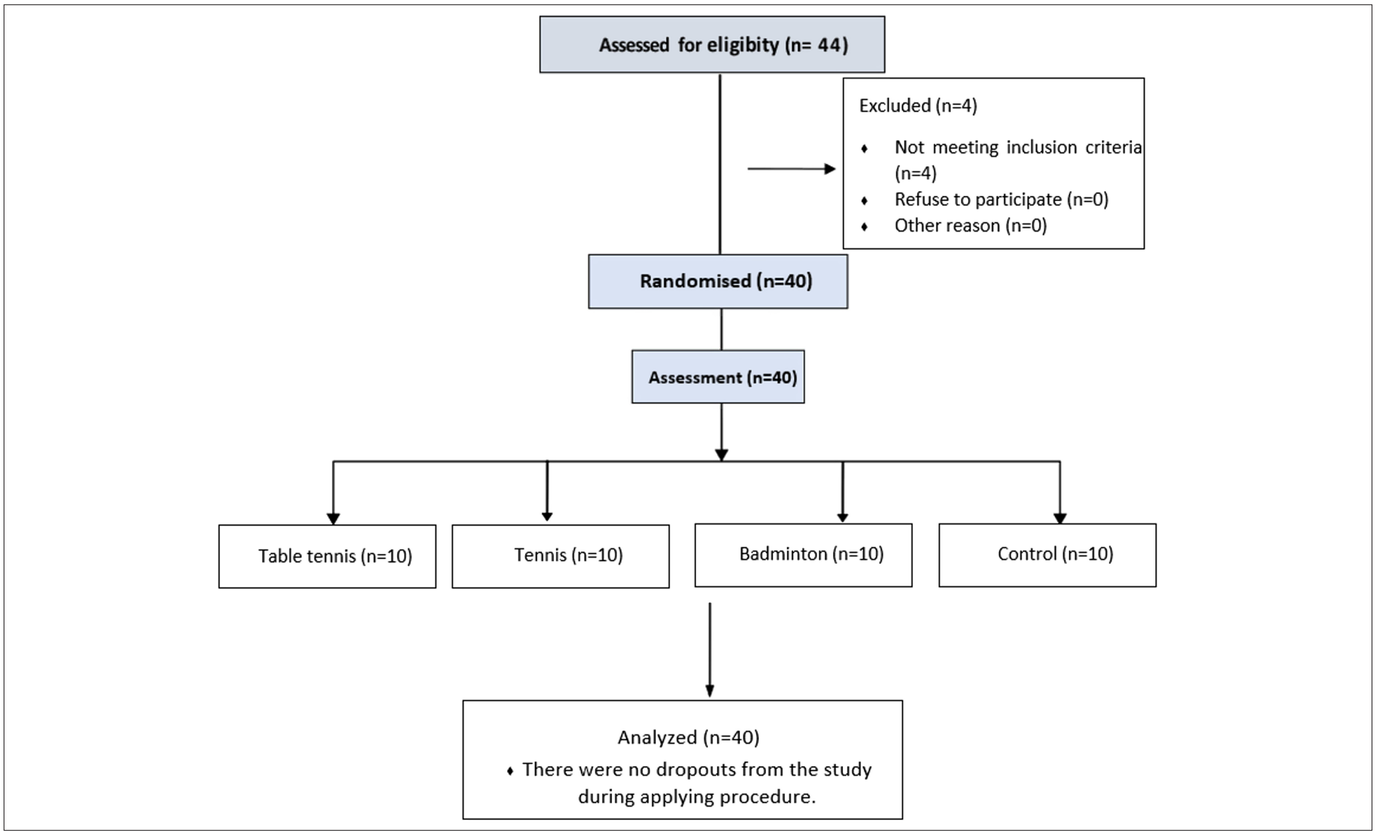

Figure 1. CONSORT diagram showing the flow of participants.

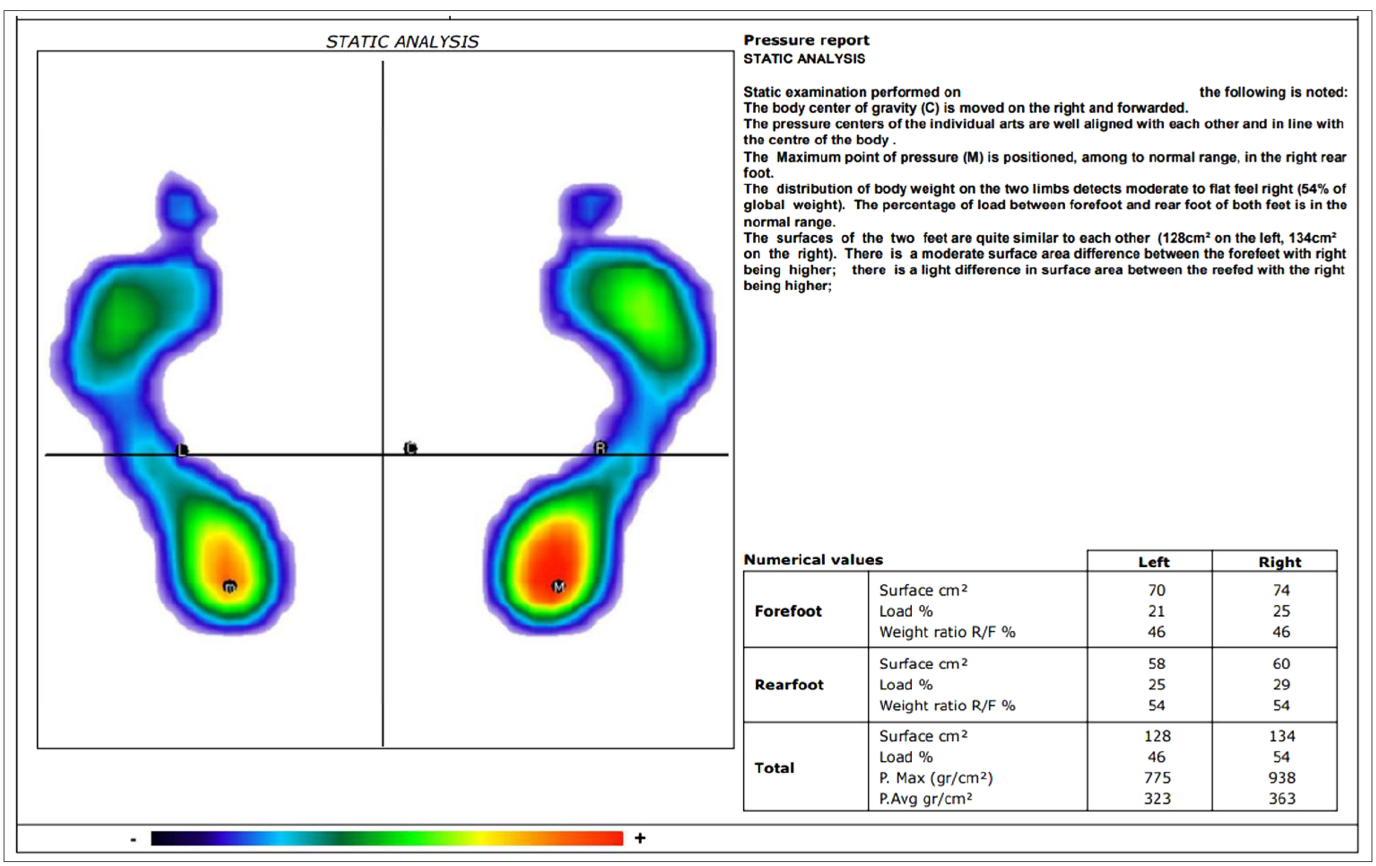

Figure 2. Example of a pedobarographic measurement.

leg touched the floor, the hands came off of the hips, or the opposite foot was removed from the stance leg. This test was conducted with eyes opened and eyes closed. The players performed 3 attempts, and the best time was recorded for analysis.[23]

Blind Stork Balance Test

Unlike the Stork Balance Test, this test was performed to evaluate the sense of proprioception. Eyes were closed, and the heel was not lifted from the ground during the test.[24]

Standing Long Jump Test

This test gives an idea of lower extremity strength, balance, flexibility, motor control, and explosive power. Before starting the test, all procedures of the test were explained. Then, while the athlete was behind the starting line, he swung his hands back and forth, bent his knees, and jumped as far as possible in the air. A tape was used to measure the straight-line distance from the starting line to the athlete's heel where he or she jumped. It was tested 3 times, and the best result was recorded.[25]

Sit-Up Test: A maximum 1-minute Sit-up Test was used to evaluate abdominal muscle endurance. The starting position consisted of lying on your back, knees bent by 90°, and feet flat on the floor. The participant's hands were placed behind his neck with his fingers crossed, the evaluator kept the participant's feet on the floor during the test. When the participant was ready, 1-minute timer started, and the participant, flexing his/her torso, raised his/her shoulders off the floor until his/her elbows touched his/her knees, then stretched out his/her torso to return to the starting position. This chain of movements is counted as a repetition. The participant did as many repetitions as possible in the 1-minute time frame, while maintaining the correct position.[26]

Statistical Analysis

IBM SPSS Statistics v.26 (Statistical Package for Social Sciences; SPSS Inc., USA) program was used to analyze the data obtained from the study. $P < .05$ was accepted as the level of significance for all statistical analyses. Differences between groups were evaluated with 1-way analysis of variance test, and Tukey HSD test was used as a post hoc test to determine the significant differences between groups. Bonferroni correction was applied for the P value in the Tukey HSD test, which was applied for post hoc tests, and the significance value was accepted as .0083 since there were 6 different pairwise comparisons.

Results

Groups' Characteristics

Each group had equal distribution regarding gender. Height, weight, and body mass index (BMI) values did not differ significantly between groups ($P > .05$). However, there was a slightly significant difference between groups in terms of "age" ($F(3.36)=4.808$; $P = .006 < .05$) (Table 1).

Pedobarographic Evaluation Results

Percentages of the forefoot, rearfoot, and total load did not differ significantly between the groups ($P > .05$) (Table 2). The pressure maximum (g/cm^2) and pressure average (g/cm^2) values for both sides did not differ significantly among the groups ($P > .05$) (Table 2).

Variation of Modified Star Excursion Balance Test Values According to Groups

A significant difference was found between groups ($P < .05$). According to the post hoc analysis, there was a significant difference between the tennis and badminton groups regarding these parameters: right posteromedical (mean values = 99.50 and 61.30; respectively), right posterrolateral (mean values = 109.30 and 74.50; respectively) and left posterolateral (mean values = 108.20 and 71.50; respectively) (Table 3).

Other Functional Performance Test Evaluation Results

There was a significant difference between groups ($P < .05$). Blind Stork Balance Test parameters of the right and left side for table tennis group were significantly higher than the control group ($P < .0083$) (Table 4).

Table 1. Characteristics of Participants

	Control	Table Tennis	Tennis	Badminton	P
Age (years)	22.00 ± 0.94[a]	20.20 ± 1.61	22.00 ± 0.81[a]	21.50 ± 1.35[a]	**.006***
Height (cm)	173.50 ± 10.53	169.00 ± 11.04	175.80 ± 8.82	172.00 ± 9.77	.502
Weight (kg)	64.40 ± 8.47	65.90 ± 20.80	69.60 ± 14.41	64.70 ± 13.47	.857
BMI (kg/m^2)	21.38 ± 2.00	22.72 ± 5.16	22.34 ± 3.29	21.64 ± 2.63	.815

*Significant differences among groups with one-way ANOVA ($P < .05$).
[a]Significantly different than table tennis ($P < .05$).
ANOVA, analysis of variance; BMI, body mass index.

Table 2. Static and Dynamic Pedobarographic Measurements (Mean ± SD)

			Control	Table Tennis	Tennis	Badminton	P
Static measurements	Forefoot load (%)	Right	17.70 ± 5.53	18.40 ± 6.15	21.00 ± 3.36	20.42 ± 5.84	.463
		Left	21.40 ± 3.50	24.60 ± 5.06	22.10 ± 3.21	23.02 ± 7.67	.550
	Rearfoot load (%)	Right	29.80 ± 3.91	28.70 ± 5.33	29.10 ± 3.17	29.10 ± 7.14	.971
		Left	31.10 ± 6.26	28.30 ± 4.52	27.80 ± 3.25	27.50 ± 5.66	.376
	Total load (%)	Right	47.50 ± 5.75	47.10 ± 4.53	50.30 ± 2.71	49.50 ± 3.20	.277
		Left	52.50 ± 5.75	52.90 ± 4.53	49.90 ± 2.47	50.50 ± 3.20	.310
Dynamic measurements	Pressure maximum (g/cm^2)	Right	2056.00 ± 348.42	1960.40 ± 378.73	2150.00 ± 318.07	2220.20 ± 417.41	.429
		Left	2160.80 ± 358.67	2145.60 ± 327.86	2239.20 ± 249.19	2053.20 ± 327.15	.635
	Pressure average (g/cm^2)	Right	885.10 ± 187.90	891.10 ± 182.78	975.80 ± 87.10	875.10 ± 115.05	.420
		Left	900.00 ± 176.47	1002.90 ± 182.52	1009.10 ± 163.57	963.40 ± 157.65	.467

Significant differences among groups with 1-way ANOVA. $P < .05$.
ANOVA, analysis of variance.

Table 3. Modified Star Excursion Balance Test Results (Mean ± SD)

		Control	Table Tennis	Tennis	Badminton	*P*
Anterior (cm)	Right	93.600 ± 21.691	93.600 ± 10.522	104.200 ± 30.839	76.200 ± 14.883	**.040**
	Left	95.900 ± 21.625	89.200 ± 8.690	104.000 ± 26.525	76.900 ± 14.263	**.022**
Posterolateral (cm)	Right	97.600 ± 22.936	94.100 ± 8.198	109.300 ± 20.892[a]	74.500 ± 25.821	**.006**
	Left	98.500 ± 22.282	88.000 ± 11.757	108.200 ± 25.486[a]	71.500 ± 22.307	**.003**
Posteromedial (cm)	Right	88.300 ± 24.000	87.200 ± 9.211	99.500 ± 34.265[a]	61.300 ± 9.844	**.004**
	Left	89.300 ± 21.914	87.600 ± 9.582	95.150 ± 32.691	67.000 ± 14.982	**.034**

Significant differences among groups with 1-way ANOVA. $P < .05$.
*Significant value was accepted as $P < .0083$ in paired group comparisons. Post hoc analysis was conducted with Tukey.
[a]Significantly different than badminton ($P < .05$).
ANOVA, analysis of variance.

Table 4. Functional Performance Evaluation Results

		Control	Table Tennis	Tennis	Badminton	*P*
Stork Balance Test (seconds)	Right	3.897 ± 2.061	25.559 ± 18.411	36.885 ± 43.362	75.773 ± 90.219	**.025**
	Left	4.214 ± 2.620	26.059 ± 22.684	34.332 ± 39.073	75.753 ± 82.834	**.014**
Blind Stork Balance Test (seconds)	Right	6.515 ± 3.825	53.165 ± 49.674[a]	19.875 ± 9.892	18.136 ± 12.993	**.002**
	Left	6.402 ± 4.501	45.90 ± 37.75[a]	18.140 ± 10.768	23.205 ± 12.582	**.011**
Standing Long Jump (cm) Test		147.700 ± 42.195	167.000 ± 43.105	171.200 ± 39.662	129.400 ± 38.112	.103
Repetitions of Sit Up		29.200 ± 17.675	23.200 ± 9.485	38.200 ± 11.564	28.400 ± 13.243	.107

Significant differences among groups with 1-way ANOVA. $P < .05$. Results are given as $x \pm$ SD. Significant value was accepted as $P < .0083$ in paired group comparisons. Post hoc analysis was conducted with Tukey.
[a]Significantly different than control.
ANOVA, analysis of variance.

Discussion

In this study, physical performance parameters with static and dynamic pressure outcomes of the foot in racquet sport players were evaluated. The number of studies comparing tennis, table tennis, and badminton players using the Modified Star Excursion Balance Test, Stork Balance Test, and Blind Stork Balance Test is either insufficient or not available.[27-29] There are very only a few studies in the literature comparing different types of racquet sports. Since the risks of injury in different lower extremity regions are defined in different racquet sports, we thought that evaluating ankle and foot parameters in different types of racquet sports and comparing their results would contribute to the literature.[15,30] Thus, we aimed to draw attention to issues such as pedobarographic and physical performance parameters in racquet sports. According to our results, static and dynamic pedobarographic parameters did not differ in tennis, table tennis, and badminton players. However, there was a significant difference between the groups regarding functional performance parameters, with the table tennis players having the best Blind Stork Balance Test results.

Foot pressure distribution and loading were important parameters, especially in athletes, and the presence of any deformity in the foot should be considered when evaluating.[31] We could not define any differences regarding static and dynamic foot pressure distributions in racquet players. There are several studies investigating static and dynamic variables of foot and ankle to identify the specialities of foot in different sports.[32,33] Girard et al[34] examined the foot pressure distribution with in-shoe portable pedobarography in different service positions in tennis players. He et al[35] claimed that the type of serve and the stance adopted by the athlete had a significant effect on the amplitude and distribution of in-shoe loading. He et al[35] examined biomechanical parameters of the lower extremities in table tennis players and found that athletes tended to keep their ankle in plantar flexion and load on their forefoot, especially while performing dynamic movements. It was also claimed that higher forces loaded on the forefoot than the rearfoot in table tennis players. Chow et al[36] investigated differences in static foot pressure in elite and sub-elite tennis players, they found that plantar pressures of elite tennis athletes tended to be concentrated in the lateral regions of the midfoot and the posterior region of both feet; however, it was distributed in the medial region of the forefoot and lateral region of the hindfoot in sub-elite athletes. Starbuck et al[37] investigated the foot pressure distributions and loadings on acrylic and clay courts by using pedobarography in the form of shoes in tennis players. They found that dynamic pressure measurements were affected by different surfaces.

According to most of the studies conducted in racquet sports, it can be said that the most foot pressure load is concentrated in the forefoot. Zhao et al.[38] in their study with 10 professional badminton and 10 amateur badminton players, found that the highest load was towards the forefoot, and the least load was towards the hindfoot. Valldecabres et al[27] examined the plantar pressure distribution of the feet according to the Y Balance Test repetitions in badminton players, it was found that the plantar pressure distribution was higher in the forefoot and toes in the pre-test evaluations. We hypothesized that there would be differences between groups regarding static or dynamic pedobarographic outcomes. However, we could not determine any significant differences in pedobarographic measurements between groups. The reason why there was no significant difference between the groups in our study may be due to several reasons. First, foot pressure measurement with wearable pedobarography may affect the results. Pedobarography outcomes recorded with wearable shoes may differ from fixed pedobarography test with the barefoot. It has also been reported that the pressure distribution varies according to the insoles and shoe type.[39] Second, it would be better to take measurements during participants performing their sports to understand the underlying mechanism of the nature of each sport.[37]

Regarding physical performance parameters, we defined statistical differences between the groups in the functional performance parameters in the Modified Star Excursion Test and Blind Stork Tests. Modified Star Excursion Test parameters were found to be higher in tennis group than in the badminton group. Blind Stork Tests were statistically higher in the table tennis group than in the control group. In the literature, there are only a few studies on physical performances in racquet sports. These studies mostly focused on physical parameters for only 1 racquet sport. Thus, to the best of our knowledge, there are not any studies comparing these parameters on different racquet sports. We detected significant differences in groups in terms of the Modified Star Excursion Balance Test and only table tennis and badminton players were found as significant. Considering pre-test results of tennis athletes in Xiong et al's[28] study, posterolateral and posteromedial results of Y Balance Test were found in better scores than their anterior balance. In another study, Y Balance Test applied by badminton players, the best balance for the pre-test, was found to be posterolateral.[29] In another study conducted to compare the visual and auditory reaction times of badminton, table tennis, and tennis players and the control group, it was found that the worst result was in the control group, while there was no significant difference between the athletes in different branches.[30] In our study, instead of the reaction time, static and dynamic balance parameters were evaluated. It is not appropriate to compare the result of these studies directly, but it can be implied that these outcomes were both related to balance and coordination.[24]

Results in functional performance evaluation indicated that there seemed a difference in mean values between racquet sport players and control group. However, we could not determine any statistically significant results between these groups. We think that this may be due to the low number of people per group. On the other hand, considering the difference between table tennis and other racquet sports in Blind Stork Balance Test, we may come up with some characteristic features of table tennis. While 'Blind Stork Balance Test' performing, the visual system is disabled, thus one needs the sense of proprioception more than any other sense. To get higher performance in table tennis, proprioceptive system of the lower extremity becomes important. Table tennis has an intermittent and explosive nature, with highly frequent and intense actions that take place around a small table.[40] In addition, table tennis players are required to hit a ball more than 30 times per minute during rallies of no longer than 4 seconds, with short resting times of less than 15 seconds. These features make table tennis a very intense sport where the ball moves at high speed and forces players to respond within milliseconds.[40] Since table tennis requires speed and agility as well as hand-eye coordination in an extremely narrow area due to the nature of table tennis, it can be thought that the sense of proprioception comes to the fore in both upper and lower extremities in table tennis players, without visual system.[24,40] That's why we may conclude that Blind Stork Balance Test in table tennis is the best test to supply information on physical performance, and this may suggest that proprioceptive input of the somatosensory system is more advanced in this type of racquet sport.[24]

Study Limitations

There are some limitations in this study. All racquet sport players in the study could be evaluated in their real environments. For further studies, real-time data and more advanced methods and equipment should be used to gather empirical information in a real competitive environment.

Conclusion

This is the first study to evaluate and compare dynamic and static foot pedobarographic results with physical performance parameters in different racquet sports. Characteristic differences regarding physical performances were found in different kinds of racquet sports. There is a need for more extensive studies on this subject.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Istanbul Medipol University (Date: December 19, 2018, Number: 10840098-604.01.01-E.53502).

Informed Consent: Written informed consent was obtained from patients/patients' parents/the parents of the patients/patient who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – XX; Design – XX; Supervision – XX; Resources – XX; Materials – XX; Data Collection and/or Processing – XX; Analysis and/or Interpretation – XX; Literature Search – XX; Writing Manuscript – XX; Critical Review – XX; Other – XX

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