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ORIGINAL ARTICLE

The Effect of Proprioceptive Neuromuscular Facilitation Stretching Exercises on Balance Circulatory Parameters and Motoric Adaptations in Futsal Players

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ABSTRACT

Background. To improve performance, athletes should try different methods. This is why the popularized proprioceptive neuromuscular facilitation (PNF) exercises are essential. **Objectives.** This study investigated the effects of 6-week PNF stretching exercises on futsal players' balance, circulatory parameters, and motoric adaptations. **Methods.** A total of 36 volunteer futsal players aged 14-17 years who regularly participated in futsal training and did not have any chronic diseases were included in the study. Futsal players were randomly divided into three groups: PNF group (n=12), training group (n=12), and control group (n=12). The PNF group received a PNF stretching exercise program three days a week for six weeks in combination with futsal training. The training group only continued futsal training regularly. No training program was applied to the control group. Age, height, weight, pulse rate, blood pressure, saturation, balance, push-ups, sit-ups, vertical jumps, horizontal jumps, sit-stand flexibility test, and 30-meter sprint test were measured in all groups. **Results.** According to the findings obtained from the study, there was a significant difference ($p<0.05$) in favor of the experimental groups in systolic blood pressure ($p=0.017$), push-ups ($p<0.001$), sit-ups ($p<0.001$), vertical and horizontal jump ($p<0.001$) and 30-meter sprint test ($p<0.001$) in PNF and training groups. While there was no statistical significance between the pre-test and post-test measurements of circulatory parameters in the PNF group, significance was found in favor of the PNF group in the intergroup comparison. **Conclusion.** When measured parameters are evaluated, we can say that PNF exercises applied to futsal players may have positive effects.

KEYWORDS: ***Proprioceptive Neuromuscular Facilitation, Circulatory, Motor Adaptation, Stretching Exercises, Futsal Players.***

INTRODUCTION

Futsal is a sport played at amateur, semi-professional, and professional levels worldwide, requiring high physical performance, technique, and tactics and emphasizing intermittent loading (1, 2). Unlimited substitutions during the match and the continuation of the duration and tempo of the game during these substitutions increase the speed and rhythm of the match (3). In futsal matches, short distance and continuous high-intensity runs involve situations where the anaerobic energy system is frequently used (4). Futsal athletes should be able to perform

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offensive and defensive principles correctly, be dynamic, and have maximum ability and harmony. Body weight and height are essential for futsal athletes to fulfill these qualities. Height is beneficial for the athlete to be fast in bilateral battles and to dominate the ball quickly. However, since futsal is a sport that requires high effort, it also requires developed muscle mass (5).

High-speed, aerobic endurance, strength, and anaerobic power are required for ball-kicking techniques, returns, and quick tackles (6, 7). A perfect harmony of body movements with the techniques used by futsal players ensures the successful realization of the intended movements. Futsal players can gain performance superiority over rival futsal players in speed, endurance, agility, physical development, and speed (8). Among the physiological factors required for a good futsal performance, speed, strength, lower extremity strength, anaerobic power, agility, and proper body composition are the leading performance characteristics (9). The harmony of the physical structure with variables affecting performance, such as strength, power, speed, flexibility, and endurance, will ensure the positive development of athlete performance (10, 11). The fact that athletes encounter the ball a lot in the game makes it necessary to have and develop characteristics such as quick decision-making, speed, and sudden change of direction (12).

Warm-up is accepted as the work done to get better efficiency from the performance of athletes, to protect from possible injuries, and to prepare and adapt to the loads to be performed in the most physiologically and psychologically appropriate way. The intensity, duration, and type of warm-up varies, and protocols are created to ensure the best adaptation and improvement in performance (13). These protocols include warm-up methods based on proprioceptive neuromuscular facilitation (PNF) techniques. PNF techniques fall under two main headings: facilitation and inhibition techniques. The main goal of PNF techniques is to improve the movement of muscles and muscle groups through facilitation and inhibition. PNF techniques, which include the use of isometric, isotonic, and eccentric muscle contractions in different ways, can be used alone or in combination with the types of contractions needed according to the level of the athlete (5, 14). PNF has a foundation used to elicit motor response, improves neuromuscular control and function, has patterns that involve multiple muscle groups, increases muscle strength and endurance, improves coordination, and improves desired function (15, 16).

This study aimed to examine the effects of 6 weeks of PNF stretching exercises on balance, circulatory parameters, and motoric adaptations of futsal players. The study aims to evaluate the potential effects of PNF on balance and motoric performance in futsal players and to provide a scientific basis for whether these techniques should be included in athletic performance programs. The necessity of the study can be explained as follows: Futsal is a sport that requires high physical performance, technique, and tactics. During futsal matches, the anaerobic energy system is frequently used, and players must excel in speed, endurance, agility, physical development, and flexibility. In this context, it is envisaged that an advanced method such as PNF can support athletes' physiological and performance development more effectively than other methods. Our study hypothesized that a-PNF stretching exercises will support the development of balance parameters of futsal players, and b-PNF stretching exercises will support the development of motoric characteristics (e.g., flexibility, strength, endurance) of futsal players.

MATERIALS AND METHODS

Experimental Approach to the Problem. A controlled experiment design model was used in the study. Power analysis was performed to determine the number of volunteers and the optimal number of participants. The subjects and their parents were informed about the study procedure and applications one week before the application. Voluntary participation certificates were obtained from the athletes, and signed consent letters were obtained from their parents regarding their participation in the study. Before the study, ethical approval was obtained from the Gaziantep University Clinical Research Local Ethics Committee with the decision dated 04.01.2023 and numbered 2022/376.

Participants. Regarding sample size was calculated using G*Power (version 3.1.9.4). The effect size was 0.4, the power was 0.80, the p-value was 0.5 for three groups and two measurements (pre-test-post-test), and the estimated total sample size was 36. According to the power analysis, 9 participants were sufficient

for each group, while injury, illness, or withdrawal from the study were considered. The study started with 12 participants for each group and 36 male volunteers. Volunteer athletes who had been active in the futsal sports team (excluding the control group) for two years were included in the study. The inclusion criteria were as follows: not having a chronic disease, participating in futsal training, being between 14-17, and not taking any doping substance. The exclusion criteria were as follows: doping or chronic drug use; history of neuromuscular disease, metabolic, hormonal, or cardiovascular disease; an orthopedic limitation; consumption of supplements such as caffeine that could interfere in the performance of the test. Descriptive data of the individuals participating in the study according to the groups are shown in Table 1.

Table 1. Descriptive data of the individuals included in the study

	Variable	N	Min.	Max.	Mean	SD.
Control Group	Age (years)	12	14	17	14.91	0.99
	Height (cm)	12	155	176	166.25	6.12
	Body Weight (kg)	12	40	69	51.66	6.66
PNF Group	Age (years)	12	14	17	15.58	0.90
	Height (cm)	12	158	185	171.08	6.38
	Body Weight (kg)	12	50	93	62.75	11.83
Training Group	Age (years)	12	14	16	15.00	0.95
	Height (cm)	12	162	186	173.33	7.04
	Body Weight (kg)	12	42	86	59.83	14.19

N: Total participants; Min: Minimum value; Max: Maximum value; SD: Standard Deviation.

Intervention. Before the study, the individuals were randomly divided into three groups. The group that participated only in the pre-test and post-test was not included in any exercise group (Control group: 12). The participants in the control group were selected from individuals who were new to futsal. Therefore, they did not train intensively in futsal as in the other groups. The group that participated in futsal training consisting of 90 minutes three days a week and continued technical and tactical training for six weeks (Training group: 12). PNF Group (n:12): This group participated in 30 minutes of PNF stretching exercises in addition to futsal training consisting of 60 minutes three days a week. 30-minute stretching exercises were performed just before the training. The muscle relaxation method applied the hamstring, internal adductor, and quadriceps muscle groups to the lower extremity.

PNF exercises will be applied to the lower extremities in the following order: First, the hamstring muscle group, then the internal adductor muscle group, and finally, the quadriceps muscle group will be targeted. The PNF movement to each muscle will be repeated for 5 sets with 10-second rest intervals. Each stage is designed to improve balance, endurance, and muscle coordination (5, 16)

Age, height, height, and body weight measurements of the athletes participating in the study were taken. Oxygen saturation measurement (SpO_2), pulse rate, blood pressure, motoric characteristics; Sit-Lie Flexibility, Horizontal Jump Test, sprint test, vertical jump test, 30 seconds push-up, and 30 seconds sit-up test; balance test measurements were recorded one week before the study and one day after the end of the study as post-test.

Circulatory Parameters Measurement. Oxygen Saturation Measurement (SpO_2): Measurements were taken using a Pulse Oximeter (Nellcor Puritan Bennet NPB - 40 brand pulse oximeter) to determine the oxygen saturation values of futsal athletes. Before starting the measurements, the athletes were informed about the pulse oximeter SpO_2 test. The oximeter probe was attached to the athlete's index finger, and measurements were taken from a sitting position. Before each measurement, the oximeter probe was disinfected, and measurements were performed (17).

Pulse rate: The pulse rates of the athletes were measured with an Acura AC - 9080K fully automatic sphygmomanometer at rest and sitting on a chair. Care was taken to ensure the athletes were comfortable and did not move during the measurements (18).

Blood pressure: The athletes' large and small blood pressures were measured with an Acura AC - 9080K fully automatic sphygmomanometer at rest and sitting. Before the measurements, the

athletes were informed about the sphygmomanometer. Care was taken to ensure the athletes were comfortable and did not stress or move during the measurements (19).

Motoric Adaptation Parameters. Sit-Reach Flexibility Test Measurement: Participants were allowed a general warm-up before the measurements to avoid injury. Athletes were allowed to warm up before the measurement process started. The prepared athletes were seated in front of the box and on the floor facing the box. The athletes were asked to rest the soles of their bare feet on the bottom of the box to reach the farthest distance by bending forward from the trunk with both hands simultaneously and to stay at the last point they could reach for a minimum of 1-2 seconds. Care was taken to ensure the athletes did not bend their knees during the movement. A third person also prevented knees from bending. Each athlete was given two attempts, and their best times were recorded (20, 21).

Horizontal Jump Test: The athlete was positioned behind the starting line with his fingertips just behind the line. He tried to jump as far as possible by spreading his feet shoulder-width apart, extending his arms and knees for power, and pushing the ground violently, and both feet of the athlete touched the ground simultaneously (22).

30-Meter Sprint Test: Athletes take their places behind the start line. Athletes were advised not to slow down as they approached the finish line. Athletes were not given a distance to accelerate at the beginning of the run but a distance to accelerate and stop at the end. Athletes were given two attempts. Running times were recorded in seconds and split seconds with a Delta SW 305 timer (Trademark origin China) (21, 23).

Vertical Jump Test: The athletes tried to jump as high as possible with both feet, bending their knees in front of a platform hanging on the wall. The standard arm length of the athlete was determined before the measurements. After the measurements, the difference between the athlete's jump and arm length was calculated, and the vertical jump distance was recorded in cm (24).

30 Second Push-Up Test: The athletes' bodies were in the frontal position, the arms were shoulder-width apart, the legs were bent at the knees, and the knees were in a ready position without touching the ground. Delta SW 305 (made in China) timer with 1/100 accuracy was used for the 30-second push-up test. As soon as the athletes felt ready, they started to do push-ups with their elbows in full extension, their chests touching the ground, and their arms in flexion, lifting the body again. Within 30 seconds, the repetitions were counted, and their degrees were recorded in units (25).

30-Second Crunch Test: In this test, the primary purpose of which is to measure trunk strength, the back of the athletes was in an upright position, the hands crossed on the chest, the heels and feet were glued to the gymnastic mat, and the knees were bent 90 degrees (16). The assistant held the athletes' feet to prevent the feet from lifting during the sit-ups. During the duration, the athletes were made to perform the movements with their hands on their neck and elbows touching their knees (26).

Flamingo Balance Test: For the Flamingo Balance Test, which is used to measure and evaluate the static balance of individuals, a 50 cm. long, 4 cm. high, and 3 cm. wide beam and two 2 cm, wide and 15 cm. long supports connected to this beam were used to ensure its stability from the top and bottom (27). The athletes tried to stay balanced on the balance beam for 1 minute. With the dominant foot bare and their free leg bent backward, they hold it with their hands on the same side. Each time the athlete's balance was disturbed, the time was paused and restarted when the athlete was in the appropriate position. A timer with 1/100 (Delta) sensitivity was used for the flamingo balance test. The number of balance disturbances made by the athletes within 1 minute was counted and recorded (25).

Statistical Analyses. The data were reported as the mean ± standard deviation (SD). The Shapiro-Wilk test was used for normality, and the Levene test was used for homogeneity. Skewness and kurtosis values were checked for data sets that did not show a normal distribution, and data sets within ±2 were considered normal (28). Mauchly Sphericity Test was used to test the sphericity assumption. Greenhouse Geiser correction was used in measurements where the sphericity assumption was not met. A 2-way repeated-measures analysis of variance (ANOVA) with a 2 x 3 design (tests x groups) was conducted with a 95% confidence interval. Post hoc testing, using the Bonferroni correction, was carried out when necessary. Effect sizes were measured using partial eta squared (ηp^2), with the following thresholds applied: ηp^2=0.01 indicating a small effect, ηp^2=0.06 indicating a medium effect, and ηp^2=0.14 indicating a significant effect. All statistical analyses were performed using Statistical Package

for the Social Sciences version 20.0 (SPSS for Windows, Chicago, Illinois, USA). A significance level of 0.05 was employed for all statistical tests.

RESULTS

Table 2 presents the statistical analysis of the average SpO_2, systolic pressure, diastolic pressure, and pulse between groups.

Significant differences between control and training groups were found in the systolic pressure post-test within the PNF trial group (CON =10.90±0.57, PNF =12.13±0.93, TRA =10.96±0.88; p=0.017). Similarly, the post-test within the diastolic pressure (CON =6.29±0.62, PNF =6.90±0.65, TRA =7.11±0.63) showed significant differences between the training and control groups (p=0.049). Post-test within the heart rate measurement in the training group (TRApost =90.25±13.43) also exhibited significant changes (p=0.003) between the pre-tests in the same group (TRApre =79.33±11.52).

Table 2. Circulatory parameters of the groups

		CON	PNF	TRA	Time		Trial		Time*Trial	
					F	p	F	p	F	p
SpO_2 (%)	Pre	95.50±1.78	96.00±1.90	94.66±1.72	2.555	0.138	0.898	0.422	3.178	0.061
	Post	95.25±2.34	96.25±1.21	94.41±1.62						
SP (mmHg)	Pre	11.48±1.40	12.48±1.39	11.30±1.25	6.328	0.029*	4.890	0.017* 2-1, 2-3	0.137	0.873
	Post	10.90±0.57	12.13±0.93	10.96±0.88						
DP (mmHg)	Pre	6.28±1.02	6.98±0.94	6.98±0.76	0.050	0.826	3.440	0.049* 1-3	0.260	0.773
	Post	6.29±0.62	6.90±0.65	7.11±0.63						
Pulse (Bpm)	Pre	78.66±14.16	79.91±11.40	79.33±11.52	14.863	0.003*	0.232	0.795	0.559	0.580
	Post	85.33±12.10	86.66±10.49	90.25±13.43						

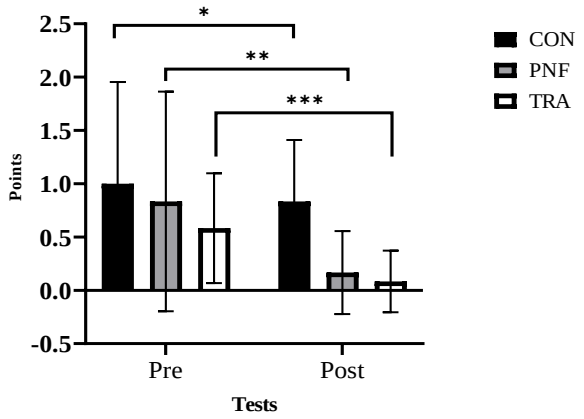
CON: control trial; PNF: proprioceptive neuromuscular facilitation trial; TRA: only training group; SP: Systolic pressure; DP: Diastolic pressure; BPM: Beats per minute; CON: 1; PNF: 2; TRA: 3; *: p<0.05.

Analysis of Motor Adaptations. The pre and post-flamingo balance test in three groups (Figure 1-a): The mean on the flamingo balance test at the post-tests was significantly lower than the pre-tests (F=12.571, p=0.005, ηp^2=0.533), (Figure 1-a). The repeated measures ANOVA results related to the flamingo balance test showed there are no significant differences for a Groups*tests interaction (F=1.540, p=0.237, ηp^2=0.123) and between groups (F=2.860, p=0.095, ηp^2=0.206). The pre and post-vertical jump test in three groups (Figure 1-b): The mean on the vertical jump test at the post-tests were significantly higher than the pre-tests (F=55.495, p=0.000 ηp^2=0.835). (Figure 1-b). The vertical jump test showed significant differences for a Groups*tests interaction (F=13.378, p=0.000, ηp^2=0.549) and significant differences for the control group between the PNF group and training group (F=21.429, p=0.000, ηp^2=0.661).

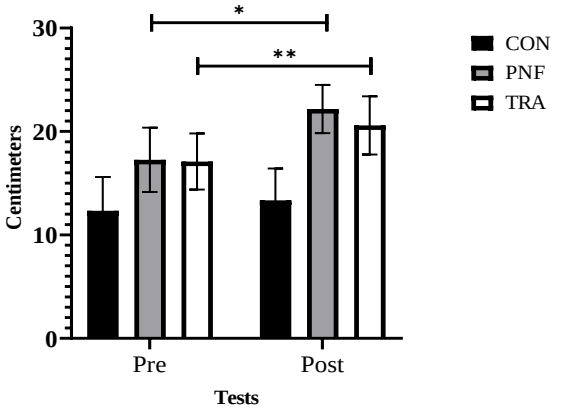
The pre and post-horizontal jump test in three groups (Figure 1-c): The mean on the horizontal jump test at the post-tests was significantly higher than the pre-tests (F=42.866, p=0.000 ηp^2=0.796). (Figure 1-c). The horizontal jump test showed significant differences for a Groups*tests interaction (F=9.304, p=0.001, ηp^2=0.458) and significant differences for the control group between the PNF group and training group (F=9.193, p=0.001, ηp^2=0.455). The pre and post-30 m sprint test in three groups (Figure 1-d): The mean on the 30m sprint test at the post-tests was significantly lower than the pre-tests (F=44.720, p=0.000 ηp^2=0.803). (Figure 1-d). The 30m sprint test showed significant differences for a Groups*tests interaction (F=7.606, p=0.003, ηp^2=0.409) and significant differences for the control group between the PNF group and training group (F=16.082, p=0.000, ηp^2=0.594).

The pre and post-push-up test in three groups (Figure 1-e): The mean on the push-up test at the post-tests was significantly higher than the pre-tests (F=49.493, p=0.000 ηp^2=0.818). (Figure 1-e). The push-up test showed significant differences for a Groups*tests interaction (F=9.205, p=0.001, ηp^2=0.456) and significant differences for the PNF group between the control group and training group (F=6.579, p=0.006, ηp^2=0.374). The pre and post-crunch tests in three groups (Figure 1-f): The mean on the crunch test at the post-tests was significantly higher than the pre-tests (F=136.761, p=0.000 ηp^2=0.926). (Figure 1-f). The crunch test showed significant differences for a Groups*tests interaction (F=9.467, p=0.003, ηp^2=0.463), and there are no significant differences between groups (F=3.696, p=0.050, ηp^2=0.251).

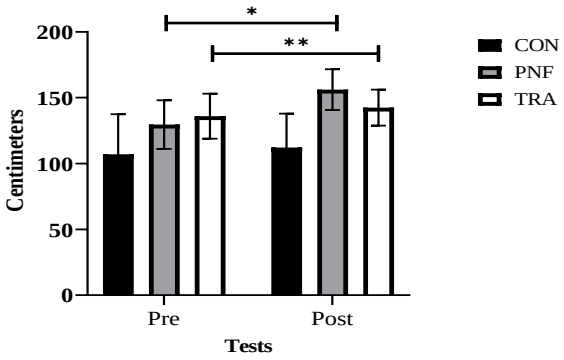
The pre and post-left sit and reach test (flexibility test) in three groups (Figure 1-g): The mean on the left sit and reach test at the post-tests were significantly higher than the pre-tests (F=106.434, p=0.000 ηp^2=0.906). (Figure 1-g). The left sit and reach test showed significant differences for a Groups*tests interaction (F=26.971, p=0.000, ηp^2=0.710), and there are no significant differences between groups (F=1.545, p=0.239, ηp^2=0.123). The pre and post-right sit and reach test (flexibility test) in three groups (Figure 1-h): The mean on the right sit and reach test at the post-tests was significantly higher than the pre-tests (F=149.074, p=0.000 ηp^2=0.931). (Figure 1-h). The right sit and reach test showed significant differences for a Groups*tests interaction (F=44.720, p=0.000, ηp^2=0.803), and there are no significant differences between groups (F=2.496, p=0.119, ηp^2=0.185).



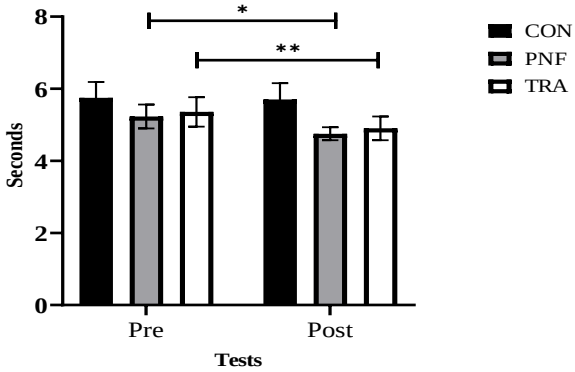
a. Flamingo balance test



b. Vertical Jump



c. Horizontal Jump



d. 30m sprint test

DISCUSSION

The main aim of this study was to investigate the effect of PNF stretching exercises on balance, circulatory parameters, and motor in futsal players during six weeks of training. We questioned whether PNF exercises applied to futsal athletes would have an extra contribution to improving performance. Our findings concluded that circulatory parameters were significant in favor of the PNF group in systolic blood pressure values and the training group in pulse rate values. In motoric characteristics, vertical and horizontal jump, flexibility, balance, sit-up, and push-up tests, significant increases were found in the intervention groups compared to the control group.

The most important findings of the study were that there was a significant difference ($p<0.05$) in favor of the experimental groups in systolic blood pressure, push-ups, sit-ups, vertical and horizontal jump, and 30-meter sprint test in the "PNF" and "Training" groups. The current study suggests that the positive effect of PNF stretching exercises may be due to factors such as an appropriate tension level of the muscles, high

motor unit activation, and high muscle electrical activity (29, 30). The main principle of PNF techniques is that physiological movements in the human body have an oblique and rotational character and that a more incredible response is achieved by movement against maximum resistance (31). Studies show that PNF practices positively affect an individual's balance performance (32-35). Pereira and colleagues had 14 people aged 60 years and older perform PNF exercise three days a week for 10 weeks and observed a statistically significant increase in balance test scores (34). One study examined the acute effects of static and dynamic stretching exercises in a study involving participants from different sports. This study used bicycle ergonomics to apply stretching exercises to the lower extremity knee and ankle muscles. Dynamic exercises were found to provide better balance performance than static exercises. However, it was not clear which exercise protocol was more effective (36). This may be due to the functional PNF techniques applied. Multiple muscle groups should be stimulated simultaneously instead of a single muscle group to achieve the desired posture, and the response time should be fast. This contraction and relaxation process can be better developed with a PNF-based warm-up. In some studies, contrary to our results, it has been concluded that static exercises do not significantly affect an individual's balance performance (37, 38).

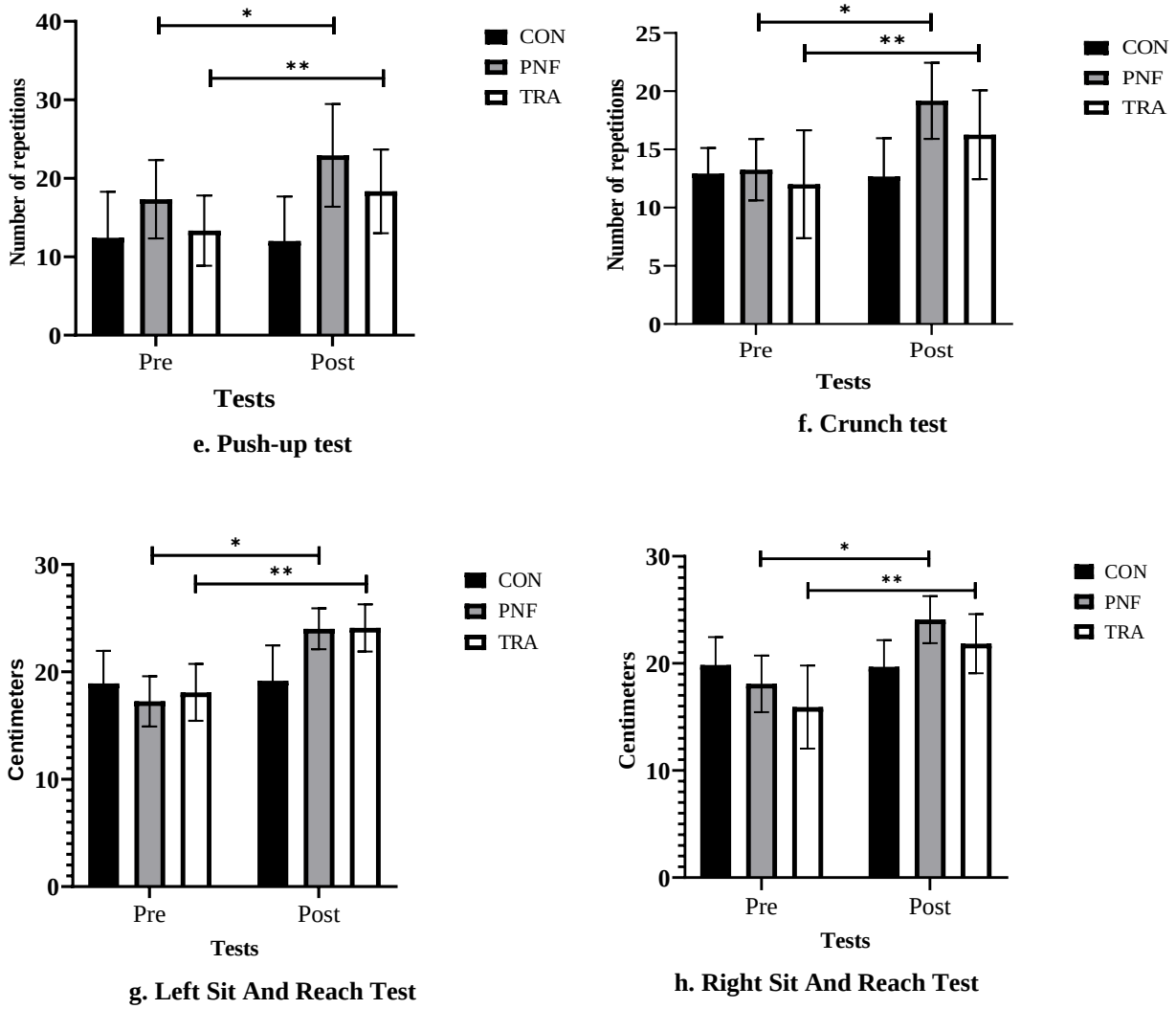


Figure 1. Statistical analysis of motoric parameters.
*: Statistical significance between pre-post test, $p<0.05$; **: Statistical significance between pre-post test, $p<0.05$; ***: Statistical significance between pre-post test, $p<0.05$.

The findings regarding the pre and post-Flamingo balance test results among the three groups (PNF, Training, Control) were as follows: In the post-tests, Flamingo balance test performance was significantly decreased compared to the pre-tests. The reasons for the lack of a significant difference in the balance parameter may be primarily the limited sensitivity or accuracy of the balance test used and the fact that other factors affecting balance (coordination, muscle strength, etc.) did not change or improve during the duration of the exercise program. A study examining athletes' balance and jumping abilities showed a positive increase in balance performance after 10 minutes of stretching exercises applied to the lower extremities (39).

When the pre and post-vertical jump test results were analyzed in the three groups, the mean vertical jump test in the post-tests was significantly higher than in the pre-tests. A study investigating the acute effects of different stretching exercises on jump performance found that the PNF stretching group achieved higher results than the control group (40). Similarly, within-group analyses showed that the jumps after PNF stretching were higher than those obtained. Serzedelo Corrêa, Pereira, and Gomes reported no significant change in vertical jump after PNF in trained women (41). The observed lack of change in vertical jump may be due to several factors. First, the effect of the exercise protocol, such as the duration, intensity, and frequency of PNF application, should be considered. Also, individual differences, such as the participants' baseline level and training history, may have influenced the results.

In the pre and post-horizontal jump tests performed on the three groups, the mean horizontal jump test in the post-tests was significantly higher than in the pre-tests. They reported an increase in long jump performance in trained female participants following PNF intervention, and this finding was consistent with our study (41). It is known that PNF stretching exercises can improve muscle performance by reducing muscle tension and allowing muscles to be properly activated. This may improve performance in activities requiring speed and power, such as horizontal jumping. In addition, PNF exercises may increase neuromuscular coordination and enable more efficient use of motor units, thus helping to perform the movement in the horizontal jump more efficiently.

When the pre and post-30 m sprint tests between the three groups were analyzed, the mean 30m sprint test score in the post-tests was significantly lower than the pre-tests. This may be due to the effect of PNF stretching exercises on reducing muscle tension. This effect makes the muscles move more freely and work more efficiently. As a result, during sprinting, the muscles work with less resistance and move faster, which can decrease sprint time. This hypothesis suggests that PNF stretching exercises may positively affect sprint performance by increasing the functional capacity of the muscles. However, more research is needed to confirm this mechanism fully. When the literature was reviewed, results contrary to our findings were observed. For example, it reported the superiority of ballistic stretching during the warm-up period compared to other methods. It found that static and PNF stretching for more than 20 seconds caused a decrease in fifty-meter sprint performance in young football players (42). In another study investigating the acute effects of active, passive, ballistic, and PNF stretching methods on young soccer players' vertical jump, sit-to-stretch, and sprint performance, no significant difference was found in 10-20-30 m sprint times (43). There may be more than one reason for these results. Factors such as the exercise protocols applied during the study, training intensity, or duration may influence the results.

Furthermore, individual characteristics of the participants, such as their starting level and training history, may also influence the results. Finally, external influences or random factors can also cause differences in results. The combination of these reasons may explain the observed decline in results.

A study investigating the short-term effects of PNF stretching exercises on young adults' blood pressure and heart rate found no significant differences in heart rate and diastolic blood pressure. However, significant changes in participants' systolic blood pressure were reported (44, 45). These results show the positive effects of PNF stretching exercises on the circulatory system and the effects of these exercises on vital functions such as blood pressure and heart rate. The circulatory system seems to work more efficiently, and applying PNF exercises regulates blood pressure and heart rate.

The mean push-up test results in the post-tests were significantly higher than in the pre-tests. The increase in the mean number of push-ups in the post-tests compared to the pre-tests indicates an improvement in the strength and endurance levels of the participants. The fact that the differences between the groups showed that the PNF group showed a more significant performance increase than the other groups may suggest that the effect of PNF on push-up performance is more effective than other methods. This may suggest that the effects of PNF stretching exercises on increasing muscle strength and endurance are significant. When the pre and post-crunch tests between the three groups were analyzed, the mean crunch test score in the post-tests was significantly higher than in the pre-tests. PNF techniques can improve flexibility in the abdominal area and help the muscles to work more effectively. Therefore, regular PNF exercises can contribute to strengthening the abdominal muscles and having a more solid abdominal area. These results may explain the improved performance of athletes in sit-ups.

When the three groups' pre-and post-test results of the flexibility test were analyzed, the mean left flexibility in the post-tests was significantly higher than in the pre-tests. When the three groups' pre-and post-test results of the flexibility test were analyzed, the mean of the right flexibil-ity test in the post-tests was significantly higher than in the pre-tests. In a study examining the effects of PNF stretching exercises applied to agonist and antagonist groups of the hamstring muscles, in parallel with our study findings, there was a significant difference in favor of post-tests in the pre and post-test performances of the groups, but no significant difference was found between the groups (46, 47). In a study examining the effect of dynamic and PNF stretching exercises applied during a 12-minute warm-up on the Cooper test and flexibility performance in athletes, significant improvements were observed for both tests, and significant differences were reported between the groups, consistent with our findings (48). In a study, the effect of static and PNF stretching techniques on soccer was investigated, and no significant difference was found in terms of stretching protocols (49). In another study, the effects of 3 different flexibility techniques, namely ballistic stretching, PNF + ballistic stretching, and PNF + static stretching, on vertical jump and explosive power were evaluated. According to the study, ballistic stretching increased vertical jump performance in individuals with low and average flexibility levels (50). Another study examined the effect of dynamic and PNF stretching on lower extremity explosive power in soccer and hockey players. Based on the study's findings, they recommended choosing a dynamic type of stretching exercise for warm-up, especially before physical activities requiring speed and strength (51).

Several possible mechanisms explain the flexibility improvement in the sit-reach test with PNF. First, PNF stretching exercises may increase the elongation and flexibility of muscle fibers. By targeting muscle fibers, these exercises provide a deeper stretch and may increase the elastic properties of muscle fibers. Second, PNF stretching exercises may increase the reflex activation of muscle fibers. This reflex activation may improve flexibility by allowing deeper stretching of muscle fibers through Golgi tendon organs and muscle spindles. Thirdly, PNF stretching exercises may increase blood flow in the muscle fibers and thus provide better nutrition to the muscle fibers, contributing to flexibility improvement. Combining these mechanisms may help PNF stretching exercises promote flexibility improvement in the sit-to-stand test.

Our study has some limitations. First, the fact that our study was conducted only with futsal players aged 14-17 years may limit the possibility of generalization. A study with a broader age range or participants from different sports would have provided comprehensive results. Another limitation is that the effects of PNF exercises were only evaluated over six weeks, which may prevent a complete understanding of the long-term effects. A study with a more extended follow-up period could have better assessed the long-term effects of PNF.

CONCLUSION

This study investigated the effects of PNF stretching exercises on balance, circulatory parameters, and motoric adaptations in futsal athletes for six weeks. Our findings revealed that PNF significantly improved performance in systolic blood pressure, push-ups, sit-ups, vertical and horizontal jumps, and 30-meter sprint tests. However, no significant improvement was observed in the balance parameter. These results suggest that PNF can improve the physical abilities of athletes but has no significant effect on balance. In particular, PNF's muscle performance-enhancing effects and improvements in specific motor skills can be considered an essential strategy in training

programs. However, the limited effect of PNF on balance emphasizes that alternative strategies should be considered in areas where balance needs to be improved. Considering the limitations of our study, future studies with larger participant groups and long-term follow-up periods are needed better to understand the effects of PNF on sports performance. Regularly practicing PNF exercises with athletes may be an essential strategy to improve their performance and reduce the risk of injury. Future research should evaluate the long-term effects of PNF exercises and examine their effects on athletes of different age groups and sports. Studies involving PNF protocols or comparing PNF with other stretching methods (traditional, static stretching) can be performed to understand PNF's efficacy better.

APPLICABLE REMARKS

- These findings are essential in supporting the development and dissemination of new training methods that can contribute to sports performance by integrating PNF stretching exercises into athlete training.
- PNF exercises should be included in training programs to improve the overall performance of athletes. Alternative balance training methods should be used in addition to PNF exercises to improve balance.
- PNF exercises should be integrated into training programs to improve motor skills, especially in young athletes. PNF exercises should be practiced regularly to improve flexibility and muscle strength in athletes.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Mustafa Ceyran, Zarife Pancar. Acquisition of data: Mustafa Ceyran, Mustafa Sencer Ulema, Mustafa Yılmaz, Ahmet Koyunlu. Analysis and interpretation of data: Mustafa Ceyran, Zarife Pancar, Burak Karaca. Drafting the manuscript: Mustafa Ceyran, Mustafa Yılmaz, Ahmet Koyunlu. Critical revision of the manuscript for important intellectual content: Mustafa Ceyran, Zarife Pancar, Mustafa Sencer Ulema, Burak Karaca, Ali Muhittin Tasdogan, Mustafa Yılmaz, Ahmet Koyunlu. Statistical analysis: Mustafa Ceyran, Burak Karaca, Mustafa Yılmaz. Administrative, technical, and material support: Mustafa Sencer Ulema, Ali Muhittin Tasdogan, Ahmet Koyunlu. Study supervision: Mustafa Ceyran, Zarife Pancar, Ali Muhittin Tasdogan.

CONFLICT OF INTEREST

There is no conflict of interest between the authors.

FINANCIAL DISCLOSURE

The researchers declared that they did not receive financial support from anywhere.

FUNDING/SUPPORT

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ETHICAL CONSIDERATION

a)informed consent was obtained from each patient included in the study and (b) the study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the institution's human research committee. Ethical approval was obtained from Gaziantep University Clinical Research Local Ethics Committee with the decision dated 04.01.2023 and numbered 2022/376.

ROLE OF THE SPONSOR

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ARTIFICIAL INTELLIGENCE (AI) USE

The authors declare that they did not use artificial intelligence technology in this study.

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