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The Effect of Static and PNF Stretching Techniques on Anaerobic Power and Balance Performance in Taekwondo Athletes: A Cross-Sectional Study

Statik ve PNF Germe Tekniklerinin Taekwondocuların Anaerobik Güç ve Denge Performansları Üzerine Etkisi: Kesitsel Araştırma

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This study was prepared based on the findings of Sinan ERDEM thesis study titled "Profesyonel Taekwondo Sporcularına Uygulanan İki Farklı Germenin Dikey Sıçrama ve Denge Üzerine Etkisi" (Düzce: Düzce University; 2024).

ABSTRACT Objective: In sports literature, warm-up plays a crucial role in preparing athletes both physiologically and psychologically to optimize their performance. While there is a consensus among researchers that warm-up practices positively influence sports performance, there remains ongoing debate about which specific stretching techniques during the warm-up phase are most effective. This study aims to investigate the effects of static and proprioceptive neuromuscular facilitation (PNF) stretching techniques, applied during the warm-up phase over an 8-week period, on the anaerobic power and static balance performance of professional taekwondo athletes. **Material and Methods:** This cross-sectional study included 30 voluntary taekwondo athletes aged between 18-25 years. The vertical jump test was used to measure anaerobic power performance, while the flamingo balance test assessed balance performance. The collected data were analyzed using IBM Statistics software. **Results:** In this study, there was no statistically significant difference between the balance and anaerobic power performances of taekwondo athletes, neither in the pre-test and post-test scores, nor between the groups ($p>0.05$). Therefore, it can be concluded that 8 weeks of static and PNF stretching techniques during the warm-up phase did not directly affect the anaerobic power and balance performance of taekwondo athletes. **Conclusion:** In conclusion, the findings highlight that neither static stretching nor PNF stretching alone is sufficient to elicit improvements in anaerobic power and balance performance in professional taekwondo athletes during the warm-up phase. Future research could refine warm-up protocols for taekwondo athletes by combining stretching and activation strategies, building on these findings.

Keywords: Warm-up; static stretching; dynamic stretching; anaerobic power; balance

ÖZET Amaç: Spor literatüründe ısınma, sporcuların fizyolojik ve psikolojik olarak en uygun şekilde hazırlanması ve performanslarını artırmaları için önemli bir rol oynamaktadır. Her ne kadar araştırmacılar arasında ısınma uygulamalarının sportif performans üzerinde olumlu etkilerinin olduğu konusunda bir fikir birliği olsa da ısınma evresinde uygulanan çeşitli germe teknikleri arasında göreceli olarak optimal germe uygulamalarının, ne olduğu konusunda tartışmalar devam etmektedir. Bu bağlamda bu araştırmanın amacı, 8 hafta boyunca ısınma evresinde uygulanan statik ve proprioseptif nöromusküler fasilitasyon (PNF) germe tekniklerinin profesyonel taekwondocuların anaerobik güç ve statik denge performansı üzerindeki etkilerini incelemektir. **Gereç ve Yöntemler:** Kesitsel tipte olan bu araştırma, 18-25 yaş arasında 30 taekwondocunun gönüllü katılımı ile gerçekleşmiştir. Katılımcıların anaerobik güç performanslarını belirlemek amacıyla dikey sıçrama testi, denge performanslarını belirlemek amacıyla ise flamingo denge testi uygulanmıştır. Araştırmada toplanan veriler, IBM istatistik yazılımı kullanılarak analiz edilmiştir. **Bulgular:** Araştırmada taekwondo sporcularının denge ve anaerobik güç performansları arasında, ne ön test ve son test skorlarında ne de gruplar arasında istatistiksel olarak anlamlı bir fark tespit edilmiştir ($p>0,05$). Dolayısı ile ısınma evresinde 8 hafta boyunca uygulanan statik ve PNF germe tekniklerinin taekwondocuların anaerobik güç ve denge performansını doğrudan etkilemediği söylenebilir. **Sonuç:** Elde edilen bulgular, ısınma aşamasında profesyonel taekwondo sporcularında anaerobik güç ve denge performansını artırmak için yalnız başına statik esneme veya PNF esneme yöntemlerinin yeterli olmadığını göstermektedir. Gelecekteki araştırmalar, bu bulgular doğrultusunda esneme ve aktivasyon stratejilerini birleştirerek taekwondo sporcuları için daha etkili ısınma protokolleri geliştirebilir.

Anahtar Kelimeler: Isınma; statik esneme; dinamik esneme; anaerobik güç; denge

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Taekwondo, which originated in Korea, has transitioned from a traditional martial art to an official Olympic sport, making it one of the most widely practiced martial arts globally.[1] In taekwondo competitions, athletes frequently use both their hands and feet to effectively engage in combat.[2] Taekwondo is a highly technical combat sport, where the athlete's explosive power, coordination, spatial awareness, psychological quality, besides performance parameters to give an example speed, flexibility, and endurance, are crucial.[3] These physical skills, which are essential for competitive environments, require significant balance abilities to be effectively executed.[4,5] Enhanced performance parameters substantially contribute to the overall effectiveness of athletes in their sport; hence, determining optimal methods to develop these skills is of great importance.[6]

Numerous studies examining the sport performance parameters in taekwondo athletes have reported that anaerobic power is a critical measure of success.[7,8] One of the key indicators of anaerobic power in taekwondo, vertical jump performance, is of significant importance.[9] Moreover, balance performance is considered one of the determinants of athletic success in taekwondo, given that many techniques are executed on one leg.[10] Considering these requirements, researchers have examined various methods to enhance anaerobic power and balance; one effective approach is the incorporation of specific stretching techniques during the active warm-up phase, which is critical for optimizing performance.[9,11,12]

In the active warm-up method, widely preferred by many athletes and coaches, various stretching techniques are utilized. Among these, static stretching (SS), which aims to enhance flexibility by holding a muscle in a fixed position at a certain point, and proprioceptive neuromuscular facilitation (PNF) stretching, where the muscle is stretched through a cycle of passive elongation and contraction-relaxation, are the most popular methods.[11] In a study by Akarsu et al. it was reported that SS did not result in a statistically significant difference in vertical jump performance, a key indicator of anaerobic power in taekwondo athletes.[9] Conversely, Alemdaroğlu et al. reported significant decreases in sprint performance, another indicator of anaerobic power, following both SS and PNF stretching in taekwondo athletes.[12] These findings are contradictory and primarily focus on acute effects. Additionally, there is limited information on how stretching techniques used during warm-up affect balance performance in taekwondo athletes. To our knowledge, there are no studies examining the long-term effects of SS and PNF stretching techniques on these parameters. Therefore, understanding how SS and PNF stretching techniques used during the warm-up phase affect the anaerobic power and balance performance of taekwondo athletes in the long term remains an important question.

Given the existing literature on static and PNF stretching techniques, further research is essential to explore their effects on balance performance, which is critical for executing techniques effectively in taekwondo. Understanding how these stretching methods influence balance could provide valuable insights for optimizing warm-up protocols and enhancing overall athletic performance. In this context, the present study aims to investigate the effects of SS and PNF stretching techniques applied during warm-up over an 8-week period on the anaerobic power and balance performance of taekwondo athletes.

MATERIAL AND METHODS

PARTICIPANTS

The sample size for this study was established using the G*Power analysis program (version 3.1.9.3, Franz Faul, Universität Kiel, Kiel, Germany). The power analysis indicated that at least 27 participants were necessary, based on an effect size of 0.50, an alpha level of 0.05, and a power of 0.80. Therefore, a total of 30 participants were included in the study, with random assignments made to either the PNF Stretching Group (PNF-G; n=15) or the SS Group (ST-G; n=15). Participant selection was conducted according to specific inclusion and exclusion criteria. The inclusion criteria were as follows: being a male taekwondo athlete aged 18-25 years with a black belt degree, having at least 3 years of professional taekwondo experience, participating in taekwondo training sessions for a minimum of 2 days per week and over 1 hour per session during the past year, hav-

ing no injury problems in the last 6 months, having no chronic health conditions, and voluntarily agreeing to participate in the study.

The exclusion criteria were as follows: not being aged 18-25 years, being an amateur taekwondo athlete, having experienced an injury problem in the last 6 months, having a chronic health condition, not attending regular taekwondo training sessions, not holding a black belt degree, identifying as female, and not consenting to participate voluntarily. Before the commencement of the study, all participants signed an informed consent form. The biometric characteristics of the participants are presented in Table 1.

RESEARCH DESIGN

This cross-sectional study was conducted following approval from the "Düzce University Scientific Research and Publication Ethics Committee" (Date: December 11, 2023, no: 2023/403) and in accordance with the Helsinki Declaration. The study utilized an experimental research model. SS and PNF stretching techniques were applied during the warm-up phase before the their main clup training phase for 8 weeks, 3 days a week (Monday-Wednesday-Friday). Prior to each stretching technique, a 5-minute low-intensity running session was performed. To assess balance performance, the flamingo balance test was conducted, while anaerobic performance was evaluated using the Vertical Jump Test. Both tests were administered twice, once at the beginning and once at the end of the study. The Vertical Jump Test was conducted prior to the Balance Test to prevent the effects of fatigue on test results. Since the Balance Test may fatigue the lower extremity muscles and the central nervous system, it could negatively influence the subsequent Vertical Jump Test. Conducting the Vertical Jump Test first allows participants to perform at their maximum capacity, thereby enhancing the validity of the measurements. A 3-minute rest period was given between performance tests. This study was conducted during the general preparation period, during which taekwondo athletes primarily focus on general conditioning and endurance training. The research plan flow chart is presented in Figure 1.

BIOMETRIC MEASUREMENTS

Body weight and height measurements were performed according to the "International Society for the Advancement of Kinanthropometry" protocol.[13] Participants' height was assessed using a wall-mounted height gauge (Holtain Ltd., UK), while body weight was recorded using an electronic scale (Seca, Germany). All measurements were taken in the morning between 09:00 and 10:00.

PERFORMANCE TEST MEASUREMENTS

In this study, athletes underwent performance tests in a specific sequence, with explosive strength tests conducted first, followed by balance tests. This order was chosen to minimize the potential influence of explosive strength and balance performance on each other, aligning with the recommendations in the literature. In this context, Hyun, Kim, and Ryew emphasized the importance of test sequencing to mitigate the effects of fatigue on various physical performance parameters in taekwondo athletes. Their study demonstrated that post-fatigue treadmill exercise significantly reduced vertical jump performance and postural stability. Specifically, parameters of ground

TABLE 1: Biometric characteristics of the participants.

Group	Variables	n	Minimum	Maximum	$\bar{X}$	SD
Static stretch group	Age (years)	15	18.00	25.00	21.33	2.66
	Height (cm)	15	172.00	184.00	177.93	3.92
	Body weight (kg)	15	66.00	80.00	71.87	4.02
PNF stretch group	Age (years)	15	18.00	25.00	21.00	2.33
	Height (cm)	15	172.00	183.00	177.47	3.11
	Body weight (kg)	15	60.00	77.00	70.00	4.10

SD: Standard deviation; PNF: Proprioceptive neuromuscular facilitation.

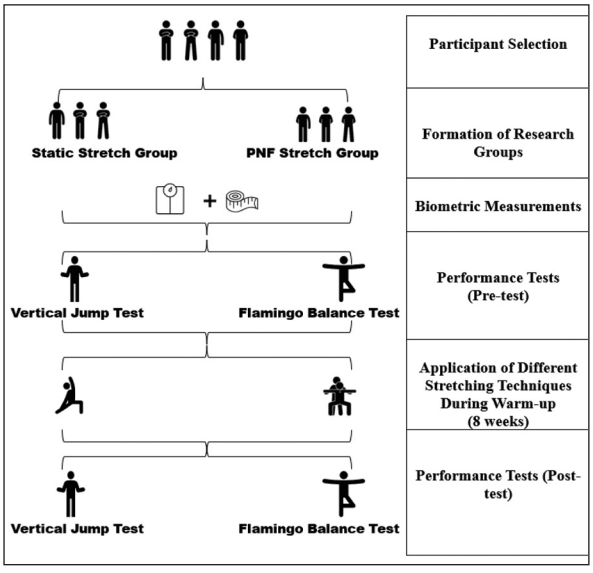

FIGURE 1: Research flow chart.

reaction forces and postural balance indices were adversely affected, revealing that fatigue impairs both dynamic and static balance as well as explosive power.[14] These findings support the notion that conducting explosive strength measurements, such as vertical jumps, prior to balance or stability tests is more appropriate during assessments or training.

VERTICAL JUMP TEST-ANAEROBIC POWER

The vertical jump test was applied to determine the anaerobic power performance of the athletes. Athletes were instructed to distribute their body weight equally on both feet and stand with their feet shoulder-width apart. Then, they were asked to reach the highest point they could on the Vertec device (Jump USA, USA), which was considered the zero starting point. Athletes were instructed to jump without taking a step, bending at the knees, hips, and ankles, and touch the highest point they could reach on the Vertec. The athletes performed the test twice, and the best value was recorded in centimeters.[15] Anaerobic power was calculated using Lewis formula. Lewis formula is presented in Figure 2.

FLAMINGO BALANCE TEST

The athletes were instructed to stand on a wooden flamingo balance platform which was 50 cm in length, 5 cm in height, and 3 cm in width (European Fitness Badge, Germany) with their dominant leg, and to bend the other leg at the knee and bring it toward their hips, holding it with their hands. This position was considered the starting and balance position. The test was paused whenever participants lost their balance (e.g., falling off the balance platform, the bent leg separating from the hip, etc.), and the time was resumed once they returned to the starting position. The test continued until the completion of a 1-minute duration. Each instance of balance loss was recorded as 1 point within the 1-minute period. A stopwatch (Seiko, Japan) was used during the measurements. The test was performed twice, and the resulting score was recorded for evaluation.[16]

STRETCHING PROTOCOLS

The application and rest durations in both the PNF Stretching Protocol and the SS Protocol were designed to ensure consistency. In the PNF protocol, which utilized the contract-relax and hold-relax techniques, each exercise lasted approximately 30 seconds. Similarly, in the SS Protocol, the duration of each exercise was also approximately 30 seconds. Additionally, the rest interval between exercises was standardized at 30 seconds. To accurately evaluate the effectiveness of the protocols and enable a fair comparison between the 2 methods, care was taken to ensure similarity in application and rest durations. The total duration of the PNF protocol was approximately 5 minutes, while the SS Protocol lasted about 6 minutes.

$$P = \sqrt{4.9 \times \text{Body Weight} \times \sqrt{D}}$$

P: Anaerobic power (in watts)

Body Weight: The person's weight in kilograms

D: Vertical jump height (in meters)

FIGURE 2: Lewis formula.

PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION STRETCHING PROTOCOL

PNF, a common stretching method using inhibition techniques, includes techniques like contract-relax and hold-relax. PNF stretching is typically performed at 100% maximum voluntary isometric contraction, recommended to be applied for 3-10 seconds.[17,18] The PNF stretching protocol involved exercises for the abdominal oblique muscles "Russian twist", adductor muscles "wide leg seated stretch", hamstring muscles "lying supine, pulling the bent leg to the chest", quadriceps muscles "lying prone, pulling the leg to the hip by bending at the knee", and gastrocnemius muscles "dorsiflexion" for 10 seconds each using the contract-relax and hold-relax technique.[19]

STATIC STRETCHING PROTOCOL

SS involves holding a joint at the end of its range of motion (pain threshold) for 15-60 seconds.[20] Static warm-up exercises were performed for 30 seconds at the sensitivity limit of the pain threshold.[21] The exercises included "Russian twist" for the abdominal muscle group, "wall chest stretch" for the pectoralis major muscle group, "wall forward bend" for the latissimus dorsi muscle group, "lying supine, pulling the bent leg to the chest" for the hamstring muscles, "lying prone, pulling the leg to the hip by bending at the knee" for the quadriceps muscles, and "dorsiflexion" for the gastrocnemius muscles.

STATISTICAL ANALYSIS

Research data were analyzed using SPSS (IBM Statistics, version 26.0, Armonk, NY, USA) software package. Descriptive statistics were used to obtain the biometric information of the participants. The normality of the data was tested using skewness and kurtosis values (±2), and the data were found to be normally distributed (Table 2).[22-24] Accordingly, the Paired Samples t-test was utilized to identify differences between the pre-test and post-test scores. The level of statistical significance was established at $p<0.05$.

In Table 2, the skewness and kurtosis results of the normality test for the groups' variables are presented. According to these results, the data are normally distributed (+2, -2).

RESULTS

The findings of the research are presented in tables below.

Table 3 shows that there were no statistically significant differences between the pre-test and post-test scores for either anaerobic power or balance performance among the participants ($p>0.05$).

TABLE 2: Normality distribution.

Grup	Variable	Skewness	Kurtosis
PNF stretching	Balance pre-test	-0.160	-1.402
	Balance post-test	0.149	-0.844
	Anaerobic power pre-test	0.153	-1.450
	Anaerobic power post-test	0.356	-0.687
Static stretching	Balance pre-test	-0.059	-1.003
	Balance post-test	-0.118	-1.174
	Anaerobic power pre-test	-0.292	-0.284
	Anaerobic power post-test	-0.290	-0.573

PNF: Proprioceptive neuromuscular facilitation.

TABLE 3: Scores for anaerobic power and balance performance.

Performance test	Group	Test	n	$\bar{X}$	SD	t value	df	p value
Anaerobic power	Static stretching	Pre-test	15	265.459	18.211	-0.650	14	0.526
		Post-test	15	266.116	17.447			
	PNF stretching	Pre-test	15	259.342	14.834	-1.263	14	0.227
		Post-test	15	260.294	13.986			
Balance	Static stretching	Pre-test	15	2.800	1.264	1.031	14	0.320
		Post-test	15	2.400	1.055			
	PNF stretching	Pre-test	15	2.800	1.373	1.169	14	0.262
		Post-test	15	2.533	0.990			

*$p<0.05$; SD: Standard deviation; PNF: Proprioceptive neuromuscular facilitation.

TABLE 4: Independent sample t-test results for the difference between the groups.

Dependent variable	Grup	n	$\bar{X}$	SD	t value	df	p value
Balance (Pre-test)	Static stretching	15	2.8000	1.26491	0.000	27.813	1.000
	PNF stretching	15	2.8000	1.37321			
Balance (Post-test)	Static stretching	15	2.4000	1.05560	-0.357	27.887	0.724
	PNF stretching	15	2.5333	0.99043			
Anaerobic power (Pre-test)	Static stretching	15	56.8000	3.29935	-0.392	27.982	0.698
	PNF stretching	15	57.2667	3.21751			
Anaerobic power (Post-test)	Static stretching	15	57.1333	3.35659	-0.348	27.484	0.731
	PNF stretching	15	57.5333	2.92445			

*p<0.05; SD: Standard deviation.

When Table 4 is analyzed, it is seen that there is no statistically significant difference between the groups in the balance and anaerobic power performance scores of the participants (p>0.05).

DISCUSSION

The aim of this study was to investigate the effects of SS and PNF stretching techniques, applied during warm-up, on anaerobic power and balance performance in taekwondo athletes over an 8-week period. The findings revealed no statistically significant improvements in balance or jump performance with either stretching technique. These results suggest that SS and PNF, when performed as part of warm-up, may not provide a performance benefit for taekwondo athletes under the given conditions. These findings present contrasting results compared to existing literature on the effects of stretching techniques, which often report performance improvements.

For example, Akarsu et al. stated that SS did not cause a significant change in the vertical jump performance of taekwondo athletes.[9] Similarly, Alemdaroğlu et al. observed that both SS and PNF stretching techniques significantly decreased sprint performance.[12] On the other hand, Cengiz et al. reported that dynamic stretching techniques caused a greater reduction in maximum anaerobic power and a significant increase in creatine kinase (CK) levels in wrestlers.[25] These differing findings suggest that the effects of stretching techniques are influenced by factors such as duration, intensity, and method of application. Moreover, these studies have examined the acute effects of stretching techniques applied during warm-up on performance. However, our current research focuses not on acute effects but on the impacts of methods applied over an 8-week period. The observed discrepancies in research findings indicate the necessity for further studies in this field.

The lack of effect found in this study could be attributed to the fact that the participants were professional-level athletes. The muscle adaptations and proprioceptive awareness of professional athletes may limit the effects of such techniques. The literature highlights that professional athletes tend to be less affected by stretching techniques due to their higher muscle elasticity and proprioceptive sensitivity.[26] In this context, it can be suggested that studies on the effects of stretching techniques should more thoroughly consider the experience level of athletes.

Another potential reason for the ineffectiveness of the stretching techniques could be related to the duration, intensity, and type of the protocols used. Franco et al. noted that 40 seconds of SS negatively impacted athletic performance, and 60 seconds of stretching led to a noticeable decrease in muscle strength.[27] Ogura et al. found that 30 seconds of stretching had no effect on muscle performance, while 60 seconds of stretching caused a significant reduction in muscle strength.[28] These findings underscore the need for further investigation into the effects of stretching duration. The impact of factors such as stretching duration, intensity, and frequency may vary depending on the athlete's adaptation level and the type of movement performed.

The lack of a significant effect of stretching techniques on balance performance observed in this study suggests that the effectiveness of these techniques may vary depending on factors such as the method of application, duration, and frequency, and that these factors could lead to different outcomes. The literature emphasizes that proprioceptive training improves balance performance and enhances neuromuscular control of the muscular system, helping to prevent injuries.[29] Consequently, the effects of stretching techniques on balance are not solely determined by their duration but also by their frequency of application and the athlete's level of expertise. Furthermore, the way athletes utilize their balance control systems in response to various environmental factors should also be considered as a potential factor explaining these findings.[30]

It should also be noted that the results of this study may have been influenced by the limitations of the research. Specifically, the fact that the stretching protocols did not directly target the same muscle groups and the minor differences between the applied protocols represent limitations in this study.

In conclusion, the results of this study indicate that neither SS nor PNF stretching significantly impacted anaerobic power or balance performance in taekwondo athletes. However, these findings highlight the need for further investigation into the influence of variables such as stretching duration, intensity, and frequency. Given the potential limitations posed by the high adaptation levels of professional athletes, it is crucial to conduct more in-depth research to better understand how various stretching techniques may affect athletic performance. Such studies are essential for refining warm-up protocols to enhance performance outcomes in high-intensity sports.

CONCLUSION

The findings of this study indicate that SS and PNF stretching techniques did not produce a significant effect on anaerobic power and balance performance in taekwondo athletes. When compared to the literature, the effects of stretching techniques on performance present mixed results, with their effectiveness varying depending on factors such as the method of application, duration, and frequency. In the present study, muscle adaptations and enhanced proprioceptive awareness in professional-level athletes may have limited the effectiveness of these techniques, as these athletes might have already reached a performance plateau. Additionally, the type and duration of the stretching protocols are important factors determining their impact on performance. In this context, it is concluded that studies on the effects of stretching techniques should be examined in greater detail. Finally, it is clear that more comprehensive research is needed to explore the effects of stretching methods on the performance of professional athletes.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Sinan Erdem, Zeynep İnci Karadenizli;* ***Design:*** *Sinan Erdem, Zeynep İnci Karadenizli, İsmail İlbak;* ***Control/Supervision:*** *Zeynep İnci Karadenizli;* ***Data Collection and/or Processing:*** *Sinan Erdem, Zeynep İnci Karadenizli, İsmail İlbak;* ***Analysis and/or Interpretation:*** *Sinan Erdem, Zeynep İnci Karadenizli, İsmail İlbak;* ***Literature Review:*** *Sinan Erdem, İsmail İlbak;* ***Writing the Article:*** *Sinan Erdem, Zeynep İnci Karadenizli, İsmail İlbak;* ***Critical Review:*** *Sinan Erdem, Zeynep İnci Karadenizli, İsmail İlbak;* ***References and Fundings:*** *Zeynep İnci Karadenizli;* ***Materials:*** *Sinan Erdem, Zeynep İnci Karadenizli, İsmail İlbak.*

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