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Effects of Different Training Methods on Selected Biomotor and Physiological Characteristics in Taekwondo Athletes

Farklı Antrenman Yöntemlerinin Taekwando Sporcularında Seçilmiş Biyomotor ve Fizyolojik Özellikler Üzerindeki Etkileri

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Abstract

The aim of this study was to investigate the effects of different training methods on selected biomotor and physiological parameters in taekwondo athletes. The research was conducted using a randomized controlled experimental design with three groups: Experimental Group 1 (taekwondo-specific plyometric training), Experimental Group 2 (taekwondo-specific resistance band training), and a Control Group (taekwondo training only). Each group followed an 8-week training program. Pre- and post-tests included assessments of balance, agility, maximal power, fatigue index, relative power, and VO2 max. In addition, striking performance was evaluated using an electronic vest during specific taekwondo techniques. Data were analyzed using SPSS 25; the Wilcoxon signed-rank test was used for within-group comparisons, and the Kruskal-Wallis test with Bonferroni-corrected post hoc analysis was applied for between-group comparisons. The resistance band group showed significant improvements in balance and agility, while the plyometric group demonstrated superior gains in maximal power, relative power, fatigue index, and VO2 max. In the striking tests, the resistance band group outperformed in paldingchagi and yopchagi techniques, whereas the plyometric group showed higher performance in the spinning paldingchagi technique.

Keywords Taekwondo, Plyometric, resistance tire, kick performance, training

ÖZ

Bu çalışmanın amacı, tekvando sporcularında farklı antrenman yöntemlerinin seçilen biyomotor ve fizyolojik parametreler üzerine etkilerini araştırmaktır. Araştırma, üç grupla rastgele kontrollü deney tasarımı kullanılarak gerçekleştirildi: Deney Grubu 1 (tekvandoya özel pliometrik antrenman), Deney Grubu 2 (tekvandoya özel direnç bandı antrenmanı) ve Kontrol Grubu (sadece tekvando antrenmanı). Her grup 8 haftalık bir eğitim programını takip etti. Ön ve son testler denge, çeviklik, maksimum güç, yorgunluk indeksi, bağıl güç ve maksimum VO2 değerlendirmelerini içeriyordu. Ayrıca belirli tekvando teknikleri sırasında elektronik yelek kullanılarak vuruş performansı değerlendirildi. Veriler SPSS 25 kullanılarak analiz edildi; grup içi karşılaştırmalarda Wilcoxon işaretli sıra testi kullanıldı ve gruplar arası karşılaştırmalarda Bonferroni düzeltmeli post hoc analizi ile Kruskal-Wallis testi uygulandı. Direnç bandı grubu denge ve çeviklikte önemli gelişmeler gösterirken, plyometrik grup maksimum güç, bağıl güç, yorgunluk indeksi ve VO2 max değerlerinde üstün kazanımlar gösterdi. Çarpışma testlerinde direnç bandı grubu paldingchagi ve yopchagi tekniklerinde daha iyi performans gösterirken, plyometrik grup spinning chagi tekniğinde daha yüksek performans gösterdi

Anahtar Kelimeler: Taekwondo, plyometrik, direnç bandı, tekme performansı, antrenman

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Introduction

There are training methods that are of great importance to maximize the performance of taekwondo athletes (Kim, 2011). It is known that some performance parameters, in particular, need to develop at a high level (Sánchez & González, 2011). Taekwondo is one of the sports branches that require different physical abilities such as high speed and explosive power, strength, balance, agility, quickness, and flexibility to be at a high level (Dello et al., 2018; Aydemir et al., 2021). One of the training methods that athletes need to take these performance parameters to a higher level and develop is plyometric training. Studies that encourage high-level speed and power production, especially explosive force development, are widely used (Apollaro et al., 2024). Plyometric training can maximize muscle contraction within the tension-contraction cycle and contribute to the development of performance parameters such as jumping, kicking, and acceleration in sports such as taekwondo (Markovic & Mikulic, 2010).

According to the information obtained from the literature, it is stated that plyometric training contributes significantly to the speed, balance, and agility performances of taekwondo athletes (Sáez et al., 2010; Xie et al., 2024; Yuan et. al., 2025). One of the most important issues of plyometric training is that the musculoskeletal system works more efficiently and is of great importance (Bishop et al.,2008). It allows the muscles to be stimulated quickly and respond faster, and allows for greater development of neuromuscular performance (Lopes et al., 2019). In sports such as taekwondo where kicking performance is important, the contributions of plyometric training to the development of kicking performance are reported (Kim, 2011).

One of the training methods to improve the performance of athletes is known as resistance band training. Resistance band training is known as an important training method for strength and power continuity by applying resistance in addition to body weight [10]. Resistance bands are of different weights and allow athletes to reach resistance levels according to their development. Resistance bands contribute to the development of desired performance parameters in sports such as taekwondo that require strength, balance, stability, and speed (Lopes et al., 2019).

Having easily accessible features facilitates access for athletes and makes it easy to achieve the desired performance (Ramirez et al., 2020). In addition, taekwondo is known as a sport where one-on-one contact is present in training and competitions. For this reason, it may carry risks of injury in joints, muscles, ligaments, and bones. According to the information obtained in the literature, it is stated that resistance band training causes strength development in muscle and connective tissues and thus can reduce the risk of injury (Bishop et al.,2008). In this study, it is aimed to examine the effects of resistance band and plyometric exercises applied to taekwondo athletes on biomotor, physiological, and taekwondo performance. There are studies in the literature that include the contribution of these training methods to the performance of athletes. Based on this information, the effects of resistance band and plyometric training on the biomotor, physiological, and kick performance of taekwondo athletes will be revealed and discussed in this study. The study is important in terms of seeing the contribution of current training met

Materials and methods

Research Model

The experimental model with a control group, which is one of the quantitative research models, was used in the research (Şimşek, 2012). Each group created in the experimental

design with a control group was determined by the random assignment method. In this model, the experimental group is subjected to an application, while the control group is not subjected to a relevant application (Mertens, 2015). In experimental design studies, it is presented as a working style created to produce solutions to the sub-problems of the study or to test the hypotheses created for the study [(Büyüköztürk, 2015).

Participation

The participants in the research consist of athletes who reside in Trabzon province and are active in the sport of taekwondo with a license in the 2022-2023 period. The athletes who participated in this research on a voluntary basis were selected from athletes whose licenses were registered at the beginning of the season and who have the criteria to compete in national competitions (at least red-black belts). Age groups were also taken into account in the inclusion of these athletes in the research, and when determining the age group, the youth category (14-17 years old) was preferred because it was the category with the highest participation in the competitions. Considering the sports ages of the taekwondo athletes who constitute the research group, it was seen that they had similar demographic characteristics and at least 5 years of taekwondo background and their participation in the research was ensured. In terms of gender, 33 of the participants were female and 33 were male. The athletes who were suitable for our research limitations were assigned to 3 separate groups by random assignment method and training and relevant measurements were performed. These groups; They were determined as Experimental Group 1 (taekwondo-specific plyometric training), Experimental Group 2 (taekwondo-specific resistance band training) and Control Group (taekwondo training)

Data Collection Tools

Information on all data collection tools used to obtain the data collected within the scope of the research is provided in this section.

Demographic Information

In order to collect demographic data of the research group, some personal information was asked in the demographic information form prepared by the researcher. With this form, information about the participants' age, gender, sports history and undergraduate registration year was collected.

Biomotor Measurements

20-Meter Speed Test: A 20-meter area was determined on a flat running surface. Marks were placed in the determined areas and a Microgate Witty branded photocell device with a sensitivity of 0.01 seconds was installed. At this stage, the participants first warmed up and made a few

trials. At the beginning of the measurement, 23 areas were determined for them to start from one meter behind the photocell and when the participants felt ready, they ran in the 20-meter area. Then, after they had a full rest, their 2nd repetition was made. Their best degrees were taken into account and recorded in seconds (Rinaldo et al., 2020).

Pro Agility (5-10-5 Agility Test): The Pro Agility test is also referred to as the 5-10-5 shuttle and is an effective change of direction test. Participants completed the test by running sideways in the marked area as desired. At the end of the test, which was repeated twice, the best score was recorded in seconds (Papagiannis et al., 2020).

Vertical Jump: The test was performed with the My Jump application, which has been previously validated and reliable (Balsalobre et al. 2015). The phone application has the ability to measure airtime and jump distance through recordings made at 240 Hz. Participants completed their warm-up before the test and performed a few repetitions. Participants completed this movement, which they started by bending their knees approximately 30 degrees on a flat surface, by jumping. The moment of the jump was recorded with a camera. The best degree of this test, which was performed with 2 repetitions, was also recorded in cm. Stork Balance: Stork balance test was used to measure the balance performance of the participants. The subjects were asked to fix their hands on their waists on a flat surface. When the participants felt ready, they were asked to rise to their toes with the supporting foot on the ground and the other foot at the knee level of the supporting foot. Releasing the hands, the foot touching the ground or the heel touching the ground were reported as the elements that ended the test. The test was applied with a stopwatch and the stopwatch was started when the athletes started. At the same time, the test was terminated when undesirable situations occurred. The results were recorded in seconds (Negra et al., 2017).

Physiological Tests

Rast (Anaerobic Based Test): Like the Wingate test, Rast was used to determine many features such as fatigue index and anaerobic power, and reliability-validity studies of this test were also conducted. For this test, a double-door photocell 25 was set up in a 35-meter flat running area. Participants completed their warm-up before the test and the test was introduced. Basically, this test consists of a running protocol repeated 6 times. The participant started running whenever he wanted and when he reached the area where the photocell was, the 1st running time was recorded. The second run was started 10 seconds later and the 2nd running time was recorded when the photocell was reached. In this way, 6 running times were recorded and the test was ended. The RAST test provides researchers with anaerobic, maximum, minimum and average power outputs, fatigue indexes and relative (peak) power values (Zagatto et al., 2009).

Yoyo (Aerobic Test): A yoyo test was applied to determine the aerobic endurance performance of the participants. The participants performed their tests with certain signals within a 20-meter area. Another 2.5-meter mark was placed behind the 20-meter mark. This area was determined as the active rest area after the 40-meter shuttle run. When the signal came, the athlete started running for the 2nd lap and continued until he got tired. The test of the participant who could not continue and was not in the marked area at the 2nd signal was terminated. According to the result, their aerobic capacities were determined (Bangsbo et al., 2008; Karakoç et al., 2012).

Taekwondo Kick Frequency Performance: It was applied to determine the kick frequency of the participants. The participants took positions in front of the Haşado brand training mannequin, which is taekwondo material. They determined their positions according to the leg length distance. The palding-chagi kick, which is the easiest technique to apply, was performed for 30 seconds at the desired distance according to the determined point and leg length angle on the Haşado brand mannequin. The foot was asked to return to the starting point after each kick for 30 seconds. The foot that went outside the desired area and the kick that went outside the target were considered invalid. The participants were allowed to use their dominant feet. The hits that were accurate at the end of 30 seconds were recorded. The techniques hit for 30 seconds were recorded with a camera. Then, the videos were divided into 5-second time periods and the number of hits was recorded (Ölmez&Yüksek, 2021).

Taekwondo Electronic Vest Strike Test: Taekwondo electronic vest strike test is one of the special tests of our study. Participants performed the techniques determined by expert trainers on electronic vests. Techniques were repeated 5 times and the bars that appeared on the computer at each strike were recorded and the best score was recorded. Participants applied each technique they applied with their right and left feet. In this study, Dadeo brand Electronic Protection Scoring Systems (PSS) were used to measure the kick power of the participants. The World Taekwondo Federation (WTF) in-tegrated technology into the combat modality in 2009, leading to a more objective scoring system. The PSS include sensors that register the number and power of the hits scored. This scoring is achieved using different sensors located in different areas of the chest pro-tector and helmet, indicating the power and location of the hits. Currently, there are only two brands approved by the WTF for such purposes, namely Daedo and KPNP. Data on the energy from valid kicks in Joules (J) are collected from an electronic monitor and made available instantly by a wireless system (Márquez et al., 2022; Del Vecchio et al., 2011).

Process and Application

The participants of Experimental Group 1 consisted of 11 males and 11 female athletes. In addition to taekwondo training 3 days a week, a planned plyometric training program was applied to this group. The training program planned as 2 hours for 6 days a week (3 days plyometric, 3 days taekwondo) was applied for 8 weeks. The participants of Experimental Group 2, which had the same characteristics, consisted of 11 males and 11 female athletes. In addition to taekwondo-specific resistance band training 3 days a week, taekwondo training was applied to the athletes of Experimental Group 2. The training program planned as 2 hours for 6 days a week was applied for 8 weeks. Finally, the control group athletes were composed of participants with the same criteria as the athletes of Experimental Group 1 and Experimental Group 2. The athletes of Control Group continued their taekwondo training planned as 2 hours for 6 days a week for 8 weeks. At the end of the 8-week training programs applied to all these participants, performance tests were applied to examine the effects on some biomotor and physiological characteristics.

Statistical analyses

After the data was transferred to the electronic environment, it was first subjected to extreme value analysis. Then, Kolmogorov-Smirnov and Shapiro-Wilk tests were performed to determine whether the data showed normal distribution. When the number of data was less than 30, Shapiro-Wilk test results were used, and when the number of data was 30 and above, Kolmogorov-Smirnov test results were used (Kalaycı, 2018). Since there were more than 30 data in this study, the Kolmogorov-Smirnov test results were used to determine whether the data showed normal distribution. Since the data did not show normal distribution, nonparametric test techniques were used in the analyses. In the intragroup (pretest-posttest) comparisons of the biomotor and physiological developments of the plyometric, resistance and control groups in the study, the Wilcoxon test was applied, and in the intergroup comparisons of the pretests and posttests of the groups, the Kruskal Wallis test was applied. In cases where the Kruskal Wallis test result was found to be significant, Bonferroni corrected Posthoc multiple comparison tests were used to determine between which groups the difference was. SPSS 25.0 statistics program was used in the analysis of the data. The significance level was determined as "$p<0.05$" in evaluating the analysis results (Kalaycı, 2018)

Results

Table 1. Comparison of Participants' Biomotor Measurements Between Groups (Pre-Test) (Kruskal Wallis)

Variety	Research Group	n	Average Rank	X^2 / KW	p	Bonferroni
Speed (sec.)	Plyometric	22	35,34			
	Resistans	22	33,75	2,05	,35	-
	Control	22	36,41			
Pro-Agility (sec.)	Plyometric	22	33,68			
	Resistance	22	34,00	4,19	,07	-
	Control	22	31,82			
Vertical Jump (cm)	Plyometric	22	32,48			
	Resistance	22	30,57	4,73	,06	-
	Control	22	29,45			
Flexibility (cm)	Plyometric	22	29,70			
	Resistance	22	31,02	4,25	**,03 ***	**2>3**
	Control	22	27,77			
Balance (sec)	Plyometric	22	31,43			
	Resistance	22	32,20	2,60	**,27**	**-**
	Control	22	30,86			

*** p<0,05; **p<0,05**

Kruskal Wallis test was applied to compare the pre-test averages of 20 m. speed, pro-agility, vertical jump, sit-and-reach and stroking balance variables according to the training method applied to the athletes. According to the test results, it was determined that there was no statistically significant difference in the pre-test rank averages of 20 m. speed, pro-agility, vertical jump, stroking balance sit-and-reach according to the type of training performed by the participants (p>0.05).

Table 2. Intergroup Comparison of Biomotor Measurements of Research Groups ANCOVA Results Regarding Pre-Test Measurements

	Sum of Squares	sd.	Mean of Squares	F	p
Group	195,71	4	48,928	,745	,621
Error	196,98	3	65,663		
Total	21459,00	22			

*** p<0,05; **p<0,05**

According to the ANCOVA test results, no significant difference between the groups could be detected.

Table 3. Intragroup (Pre-Test-Post-Test) Comparison of Participants' Biomotor Measurements (Wilcoxon)

	Variety	Measurement	n	Average Rank	Total Rank	Z	p
Plyometric	Speed (20 m. Speed) (sn)	Negative Order	21	12,00	252,00		
		Pozitive Order	1	1,00	1,00	**-4,077**	**,000****
		Equal	0				
	(Pro-Agility) (sn)	Negative Order	22	11,50	253,00		
		Pozitive Order	0	,00	,00	**-4,110**	**,000****
		Equal	0				
	Vertical Jump (cm)	Negative Order	1	14,50	14,50		
		Pozitive Order	14	7,54	105,50	**-2,620**	**,009****
		Equal	7				
	Flexibility (cm)	Negative Order	0	,00	,00		
		Pozitive Order	17	9,00	153,00	**-3,637**	**,000****
		Equal	5				
	Balance (sn)	Negative Order	0	,00	,00		
		Pozitive Order	22	11,50	253,00	**-4,107**	**,000****
		Equal	0				
Resistans	Speed (20 m. Speed) (sn)	Negative Order	22	11,50	253,00		
		Pozitive Order	0	,00	,00	**-4,110**	**,000****
		Equal	0				
		Negative Order	22	11,50	253,00		

Control	(Pro-Agility) (sn)	Pozitive Order	0	,00	,00	**-4,110**	**,000****
		Equal	0				
		Negative Order	0	,00	,00		
	Vertical Jump (cm)	Pozitive Order	22	11.50	253.00	**-4,179**	**,000****
		Equal	0				
		Negative Order	0	,00	,00		
	Flexibility (cm)	Pozitive Order	22	11,50	253,00	**-4,127**	**,000****
		Equal	0				
		Negative Order	0	,00	,00		
	Balance (sn)	Pozitive Order	22	11,50	253,00	**-4,107**	**,000****
		Equal	0				
		Negative Order	17	11,26	191,50		
	Speed (20 m. Speed) (sn)	Pozitive Order	3	6,17	18,50	**-3,233**	**,001****
		Equal	2				
		Negative Order	19	11,00	209,00		
	(Pro-Agility) (sn)	Pozitive Order	1	1,00	1,00	**-3,896**	**,000****
		Equal	2				
		Negative Order	1	3,00	12,00		
	Vertical Jump (cm)	Pozitive Order	11	6,00	54,00	**-2,111**	**,035***
		Equal	10				
		Negative Order	0	,00	,00		
	Flexibility (cm)	Pozitive Order	19	10,00	190,00	**-3,838**	**,000****
		Equal	3				
		Negative Order	6	5,25	31,50		
	Balance (sn)	Pozitive Order	16	13,84	221,50	**-3,085**	**,002****
		Equal	0				

*** p<0,05; **p<0,05**

Wilcoxon Signed Ranks test was applied to determine whether there was a significant difference between the 20 m. speed, pro-agility, vertical jump, sit-reach and stroking balance pre-test and post-test scores of the athletes in the plyometric, resistance and control groups. As a result of the analysis, when the rank average and rank totals of all groups were examined, it was determined that the pre-tests were statistically significantly higher than the post-tests in the 20 m. speed and pro-agility measurements ($p<0.05$). In the vertical jump, sit-reach and stroking balance tests, it was seen that the post-tests were statistically higher than the pre-tests ($p<0.05$).

Table 4. Comparison of Participants' Biomotor Measurements Between Groups (Post-Test) (Kruskal Wallis)

Variety	Research	n	Average	X^2/	p	Bonferroni
Speed (20 m Speed) (sn)	Plyometric	22	39,70	2,973	,226	-
	Resistans	22	36,66			
	Control	22	33,14			
Pro-Agility (sec.)	Plyometric	22	34,27	4,289	,117	-
	Resistans	22	40,41			
	Control	22	32,82			
Vertical Jump (cm)	Plyometric	22	40,61	5,287	,071	-
	Resistans	22	38,41			
	Control	22	35,48			
Flexibility (cm)	Plyometric	22	26,23	17,386	**,000****	**2>1**
	Resistans	22	47,41			
	Control	22	26,86			
Balance (sec.)	Plyometric	22	35,07	8,427	**,015***	**2>3**
	Resistans	22	41,00			
	Control	22	24,43			

*** p<0,05; **p<0,05**

The Kruskal Wallis test results, which were conducted to compare the post-test means of 20 m. speed, pro-agility, vertical jump, sit-reach and sprint balance variables according to the applied training method of the athletes, are shown in TABLE 4. Kruskal Wallis test was applied to compare the post-test means of 20 m. speed, pro-agility,

vertical jump, sit-reach and sprint balance of the athletes participating in the study according to the applied training type. According to the test results, it was determined that there was no statistically significant difference in the 20 m. speed, pro-agility and vertical jump means of the participants according to the type of training they underwent (p>0.05). However, it was observed that there was a statistically significant difference in the post-test means of sprint and sprint balance according to the type of training they underwent (p<0.05). Corrected Bonferroni was used to find the group that made the difference. As a result, it was observed that the mean ranks of the resistance training group were higher than the mean ranks of both the plyometric and control groups in the sit-reach post-test measurements. In the post-test measurements of stork balance, it was observed that the mean rank of the resistance training group was higher than the mean rank of the control group.

Tablo 5. Intergroup (Pre-Test) Comparison of Participants' Anaerobic (Running Based Test) and Aerobic (Yo-Yo Test) Endurance Measurements (Kruskal Wallis)

Variety	Research Group	n	Average Rank	X^2 / KW	p
Max. Strenght	Plyometric	22	35,05	2,756	,252
	Resistans	22	33,11		
	Control	22	32,34		
Min. Strenghy	Plyometric	22	37,73	3,563	,214
	Resistance	22	35,75		
	Control	22	39,02		
Avarage Strenght	Plyometric	22	35,55	3,609	,165
	Resistance	22	30,27		
	Control	22	37,68		
Fatigue Index	Plyometric	22	32,05	,219	,896
	Resistance	22	34,73		
	Control	22	33,73		
Relative Strenght	Plyometric	22	33,57	3,162	,246
	Resistance	22	28,30		
	Control	22	37,64		
MaxVO2	Plyometric	22	37,18	2,876	,284
	Resistans	22	39,25		
	Control	22	36,05		

*** p<0,05; **p<0,05**

Kruskal Wallis test was applied to compare the pre-test rank averages of max. power, min. power, average power, fatigue index and relative power of the athletes participating in the study according to the type of training applied. According to the test result, it was determined that there was no statistically significant difference in the max. power, min. power, average power, fatigue index, relative power and maxVo2 rank averages of the participants according to the type of training perormed (p>0.05)

Table 6. Intra-Group (Pre-Test-Post-Test) Comparison of Participants' Anaerobic (Running Based Test) and Aerobic (Yo-Yo Test) Endurance (Wilcoxon)

	Variety	Measurement	n	Average Rank	Total Rank	Z	p
Plyometric	Max. Strenght	Negative Order	3	7,00	21,00	**-3,425**	**,001****
		Pozitive Order	19	12,21	232,00		
		Equal	0				
	Min. Strenghy	Negative Order	1	1,00	1,00	**-4,074**	**,000****
		Pozitive Order	21	12,00	252,00		
		Equal	0				
	Avarage Strenght	Negative Order	0	,00	,00	**-4.107**	**,000****
		Pozitive Order	22	11,50	253,00		
		Equal	0				
	Fatigue Index	Negative Order	7	12,57	88,00	-1,250	,211
		Pozitive Order	15	11,00	165,00		
		Equal	0				
	Relative Strenght	Negative Order	1	7,50	10,50	**-3,767**	**,001****
		Pozitive Order	21	12,00	242,50		
		Equal	0				
	MaxVO2	Negative Order	0	,00	,00	**-4,109**	**,000***
		Pozitive Order	22	11,50	253,00		
		Equal	0				
Resistance	Max. Strenght	Negative Order	0	,00	,00	**-4,107**	**,000****
		Pozitive Order	22	11,50	253,00		
		Equal	0				

	Min. Strenghy	Negative Order	0	,00	,00	**-4,107**	**,000****
		Pozitive Order	22	11,50	253,00		
		Equal	0				
	Avarage Strenght	Negative Order	0	,00	,00	**-4,107**	**,000****
		Pozitive Order	22	11,50	253,00		
		Equal	0				
	Fatigue Index	Negative Order	7	7,00	49,00	**-2,516**	**,012****
		Pozitive Order	15	12,60	204,00		
		Equal	0				
	Relative Strenght	Negative Order	0	,00	,00	**-4,107**	**,000****
		Pozitive Order	22	11,50	253,00		
		Equal	0				
	MaxVO2	Negative Order	0	,00	,00	**-4,108**	**,000***
		Pozitive Order	22	11,50	253,00		
		Equal	0				
Control	Max. Strenght	Negative Order	3	6,33	19,00	**-3,490**	**,000****
		Pozitive Order	19	12,32	234,00		
		Equal	0				
	Min. Strenghy	Negative Order	4	3,75	15,00	**-3,620**	**,000****
		Pozitive Order	18	13,22	238,00		
		Equal	0				
	Avarage Strenght	Negative Order	2	6,50	13,00	**-3,685**	**,000***
		Pozitive Order	20	12,00	240,00		
		Equal	0				
	Fatigue Index	Negative Order	8	6,50	52,00	**-2,419**	**,016****
		Pozitive Order	14	13,00	201,00		
		Equal	0				
	Relative Strenght	Negative Order	3	5,00	15,00	**-3,493**	**,000****
		Pozitive Order	18	12,00	216,00		
		Equal	1				
	MaxVO2	Negative Order	0	,00	,00	**-4,114**	**,000***
		Pozitive Order	22	11,50	253,00		
		Equal	0				

*** p<0,05; **p<0,05**

In order to determine whether there is a significant difference between the pre-test and post-test scores of athletes in plyometric, resistance and control groups in terms of maximum power, minimum power, and average power, fatigue index, relative power and maxVo2, Wilcoxon Signed Ranks test was applied. As a result of the analysis, when the average rank and total ranks of athletes in the plyometric group were examined in all groups and tests except for the fatigue index variable (p>0.05), it was determined that the post-tests were statistically significantly higher than the pre-tests (p<0.05). Accordingly, it can be said that the trainings done by the groups increased their post-tests.

Table 7. Comparison of Participants' Anaerobic (Running Based Test) and Aerobic (Yo-yo Test) Endurance Measurements between Groups (post-test) (Kruskal Wallis)

Variety	Research Group	n	Average Rank	X^2 / KW	p	Bonfer.
Max. Strenght	Plyometric	22	39,11	,382	**,01****	**1>3**
	Resistans	22	30,66			
	Control	22	23,20			
Min. Strenghy	Plyometric	22	31,09	,145	,93	-
	Resistans	22	30,18			
	Control	22	40,23			
Avarage Strenght	Plyomettic	22	32,18	,183	,91	-
	Resistans	22	34,64			
	Control	22	33,68			
Fatigue Index	Plyometric	22	44,50	1,701	**,00****	**1>3**
	Resistans	22	34,00			
	Control	22	27,00			
Relative Strenght	Plyometric	22	44,77	,803	**,00****	**1>3**
	Resistans	22	35,25			
	Control	22	28,48			
MaxVO2	Plyometric	22	44,39	,882	**,00****	**1>3**
	Resistans	22	36,27			
	Control	22	28,84			

p<0,05; **p<0,01

The Kruskal Wallis test was applied to compare the post-test rank averages of max. power, min. power, average power, fatigue index, relative power and maxVo2 of the

athletes participating in the study according to the type of training applied. According to the test result, it was determined that there was no statistically significant difference in min. power and average power, rank averages ($p>0.05$). It is seen that there is a statistically significant difference in the post-test rank averages of max. power, fatigue index, relative power and maxVo2 according to the type of training performed ($p<0.05$). Corrected Bonferroni was used to find the group that made the difference. As a result, it is seen that the rank averages of the plyometric training group are higher than the rank averages of both the resistance and control groups.

Table 8. Intergroup (Pre-Test) Comparison of Participants' Taekwondo Kick Frequency Performance Test Protocol Test Measurements (Kruskal Wallis)

Variety	Research Group	n	Average Rank	X^2/ KW	p
0-5 sec.	Plyometric	22	32,98	,02	,98
	Resistans	22	33,68		
	Control	22	33,84		
5-10 sec	Plyometric	22	31,73	,33	,84
	Resistance	22	34,98		
	Control	22	33,91		
5-15 sec	Plyometric	22	33,43	,01	,99
	Resistance	22	33,16		
	Control	22	33,91		
15-20 sec	Plyometric	22	33,00	,47	,79
	Resistance	22	31,84		
	Control	22	35,66		
20-25 sec	Plyometric	22	29,30	1,66	,43
	Resistance	22	35,73		
	Control	22	35,48		
25-30 sec	Plyometric	22	33,66	,03	,98
	Resistans	22	32,91		
	Control	22	33,93		
Total	Plyomet	22	32,23	,17	,91
	Resistans	22	33,61		
	Control	22	34,66		

The Kruskal Wallis test was applied to compare the 0-5 sec., 5-10 sec., 5-15 sec., 15-20 sec., 20-25 sec., 25-30 sec. and total technical pre-test rank averages of the athletes participating in the study according to the type of training applied. According to the test results, it was determined that there was no statistically significant difference in the 0-5 sec., 5-10 sec., 5-15 sec., 15-20 sec., 20-25 sec., 25-30 sec. and total technical pre-test rank averages of the participants according to the type of training applied ($p>0.05$).

Table 9- Comparison of Participants' Taekwondo Kick Frequency Performance Test Protocol Test Measurements Between Groups (Post-Test) (Kruskal Wallis)

Variety	Research Group	n	Average Rank	X^2	p
0-5 sec.	Plyometric	22	34,77	1,88	0,39
	Resistans	22	37,59		
	Control	22	30,14		
5-10 sec	Plyometric	22	34,52	0,71	0,7
	Resistans	22	35,23		
	Control	22	30,75		
5-15 sec	Plyometric	22	36,5	1,53	0,46
	Resistans	22	36,34		
	Control	22	29.66		
15-20 sec	Plyometric	22	37.09	0,91	0,63
	Resistans	22	36.64		
	Control	22	31.77		
20-25 sec	Plyometric	22	36.05	4,31	0,11
	Resistans	22	34.30		
	Control	22	30.16		
25-30 sec	Plyometric	22	37.70	4,56	0,1
	Resistans	22	33.34		
	Control	22	27.45		

Total	Plyometric	22	38.93	1,39	0,49
	Resistans	22	36.68		
	Control	22	29,89		

The Kruskal Wallis test was applied to compare the 0-5 sec., 5-10 sec., 5-15 sec., 15-20 sec., 20-25 sec., 25-30 sec. and total technical post-test rank averages of the athletes participating in the study according to the type of training applied. According to the test results, it was determined that there was no statistically significant difference in the 0-5 sec. 5-10 sec., 5-15 sec., 15-20 sec., 20-25 sec., 25-30 sec. and total technical post-test rank averages of the participants according to the type of training applied ($p>0.05$).

Tablo 10: Intergroup (Pre-Test) Comparison of Participants' Taekwondo Technical Performance Test Measurements (Kruskal Wallis)

Variety	Research Group	n	Average Rank	X^2/ KW	p
Palding-Chagi Right	Plyometric	22	28,05	3,40	,18
	Resistans	22	33,75		
	Control	22	38,70		
Palding-Chagi Left	Plyometric	22	26,98	3,85	,145
	Resistans	22	36,18		
	Control	22	37,34		
Yop-Chagi Right	Plyometric	22	35,91	,52	,76
	Resistans	22	32,52		
	Control	22	32,07		
Yop-Chagi Left	Plyometric	22	34,32	,30	,85
	Resistans	22	31,66		
	Control	22	34,52		
Spin Palding-Chagi Right	Plyometric	22	27,89	3,96	,138
	Resistans	22	33,23		
	Control	22	39,39		
Spin Palding-Chagi Left	Plyometric	22	29,82	1,61	,44
	Resistans	22	33,52		
	Control	22	37,16		

In order to determine whether there is a significant difference between the pre-test and post-test scores of the athletes in the plyometric, resistance and control groups for palding right, palding left, yopchagi right, yopchagi left, burgu right and burgu left, Wilcoxon Signed Ranks test was applied. As a result of the analysis, when the mean rank and total ranks were examined in all groups and tests except the yopchagi left test in the control group ($p>0.05$), it was determined that the post-tests were statistically significantly higher than the pre-tests ($p<0.05$). Accordingly, it can be said that the trainings done by the groups increased their post-tests.

Table 11: Comparison of Participants' Taekwondo Technical Performance Test Measurements Between Groups (Post-Test) (Kruskal Wallis)

Variety	Research Group	n	Average Rank	X^2/ KW	p	Bonferroni
Palding-Chagi Right	Plyometric	22	30,16	1,21	**,08****	**2>1**
	Resistans	22	42,50			

Palding-Chagi Left	Control	22	25,84	4,51	**,07****	**2>1**
	Plyometric	22	30,05			
	Resistans	22	39,27			
Yop-Chagi Right	Control	22	22,18	3,61	**,00****	**2>1**
	Plyometric	22	31,75			
	Resistans	22	42,59			
Yop-Chagi Left	Control	22	27,16	1,76	,41	-
	Plyometric	22	33,98			
	Resistans	22	33,39			
Spin Palding-Chagi Right	Control	22	29,14	3,26	**,04***	**1>2**
	Plyometric	22	44,66			
	Resistans	22	37,73			
Spin Palding-Chagi Left	Control	22	25,11	2,81	,24	-
	Plyometric	22	34,82			
	Resistans	22	33,50			
	Control	22	33,18			

The Kruskal Wallis test was applied to compare the post-test rank averages of palding right, palding left, yopchagi right, yopchagi left, burgu right and burgu left of the athletes participating in the study according to the type of training applied. It was determined that there was no statistically significant difference in the rank averages of Yopchagi Left and Burgu Left ($p>0.05$). It was observed that there was a statistically significant difference in the post-test rank averages of paldingchagi right and left, yopchagi right and burgu right according to the type of training performed ($p<0.05$). Corrected Bonferroni was used to find the group that made the difference. As a result, it was seen that the rank averages of the resistance band training group of paldingcahi right and left and yopchagi right techniques were higher than the rank averages of both the plyometric and control groups. It was seen that the spin paldingchagi technique was higher in the plyometric training group compared to the resistance and control groups.

Discussion and Conclusion

The current study investigated the comparative effects of plyometric and resistance band training on biomotor, physiological, and technical performance in taekwondo athletes. Baseline measurements showed no significant differences among groups. However, post-test results indicated significant improvements in balance and flexibility in the resistance band group, while the plyometric group showed marked enhancement in explosive strength and aerobic performance.

Taekwondo is a sport in which there is especially kick frequency, technical speed and technical continuity within the loop of the neuromuscular system (Ouergui et al., 2022) This situation reveals that taekwondo athletes should be trained well and all biomotor, physiological and technical performance parameters

should be developed. It is seen in the literature that taekwondo training is planned and implemented in this direction (Yoo et al.,2018; Li et. al., 2024; Khazaei et al., 2023).

In our study, it is seen that the participants who did plyometric training showed more development in rotational and sequential techniques, while the groups who trained with resistance bands showed more development in direct and explosive kicks. There are studies similar to our study in the literature and it has been seen that they support our study (Ouergui et al., 2022; Messaoudi et al., 2024). According to the results obtained from the findings of the study, it is seen that the effects of different training types on biomotor, physiological and technical performance parameters are significantly different, but there is no development in some performance parameters. According to

the data obtained, it is seen that athletes who do plyometric training show more effective results in speed, agility, explosive power, and athletic techniques, while athletes who do resistance band training show more development in flexibility, balance and performance parameters where direct explosive hits are made. There are studies supporting our study in the literature [39, 4, 40]. In this study, the effects on biomotor, physiological and technical performance were examined in depth according to the training program applied to the participants and physical abilities were revealed. According to the results obtained, information that will contribute to training strategies is provided.

When the within-group (pre-test–post-test) comparisons of the participants' motor characteristics were examined, the results of the speed (20 m), agility (Pro Agility), vertical jump, flexibility (Sit-and-Reach), and balance (Stork) tests were found to be significant for all groups.

When the between-group (pre-test–post-test) comparisons of the participants' motor characteristics were analyzed, a significant improvement was detected in flexibility performance. Flexibility is one of the key parameters in taekwondo. The effectiveness of techniques applied to the opponent's head level, kicks delivered at different angles, the transfer of strength during execution, and combined techniques all highlight the importance of flexibility. Studies in the literature emphasize the significance of flexibility for taekwondo (Fong & Tsang, 2012). According to the adjusted Bonferroni Sit-and-Reach test results, which were used to determine which group showed the most improvement, the experimental group that performed taekwondo-specific resistance band training showed greater progress in flexibility compared with the plyometric and control groups.

Balance performance, as in many sports, is one of the fundamental parameters of dynamic sports such as taekwondo. Maintaining the desired body composition and postural balance during consecutive techniques and sudden changes of direction is crucial. Previous studies have also highlighted the importance of balance performance in sports like taekwondo (Tetik, 2013). Similar to the flexibility results, balance test outcomes favored the participants in the taekwondo-specific resistance band group. This indicates that the post-test flexibility and balance results were in favor of the group performing resistance band training. Studies on balance performance show that resistance band exercises contribute to balance development (Kwak et al., 2016). It is stated in the literature that resistance band training improves muscle endurance, muscle strength, and balance (Hernandez et al., 2024). Based on the findings of this research and previous literature, including taekwondo-specific resistance band programs in taekwondo training can support the development of balance and flexibility performance.

Performance factors such as speed, jumping, and agility, like other performance parameters, vary from person to person. According to the findings of our study, there were no significant differences between groups in the 20 m sprint, agility, and vertical jump test results. The fact that participants had similar training histories, displayed similar characteristics, and the nature of taekwondo itself are thought to have influenced the absence of significant differences between groups. When reviewing similar and contrasting studies, Christensen et al. (2020) reported that resistance band training did not affect agility performance, which is consistent with our findings. In our study, no significant difference was found in agility performance between groups performing resistance band training. A six-week study involving 30 male taekwondo athletes reported positive effects of plyometric training on agility performance (Singh et al., 2015). Davaran et al. (2014) also noted that six weeks of plyometric training had positive effects on athletes' agility. These findings differ from ours, likely because participants in

our study shared similar training histories, were competitive athletes, and maintained consistent training.

Regarding speed performance, our study found no significant differences between groups. In the literature, Saygın et al. (2005) reported no significant differences between groups in a 12-week plyometric study. Similarly, Christensen et al. (2020) found no significant differences in speed performance among participants who trained with resistance bands. These studies support our results. Conversely, Davaran et al. (2014) reported improvements in sprint performance after plyometric training. These differences may stem from the similar characteristics and training histories of all participants in our study.

When examining the between-group comparisons of vertical jump performance, no significant differences were detected. Studies on vertical jump performance indicate that resistance band training had no effect in a study on 20 female volleyball players (Durukan & Göktepe, 2020). Similarly, Atan (2019) reported no effect of resistance band training on vertical jump performance in 30 basketball players. These studies align with our findings. Other research, such as Singh et al. (2015) and Lara-Sanchez et al. (2011), reported positive effects of plyometric training on vertical jump performance, which differs from our study.

Within-group and between-group comparisons were made in our study, and the developments were reported. Based on these findings and the literature, the within-group improvements of participants in the plyometric, resistance band, and control groups were evaluated. This indicates that the significant values obtained at the end of each training program reflect appropriate training approaches. In other words, improvements were observed in all groups: plyometric, taekwondo-specific resistance band, and taekwondo-only training. These results suggest that plyometric, resistance band, and standard taekwondo training can all be considered viable for motor performance development. However, between-group comparisons revealed similar outcomes, except for flexibility and balance, which favored the resistance band group. Additionally, since taekwondo is a complex sport that includes jumps, explosive techniques, and sudden direction changes, and because the athletes were of similar age, background, and training environment, differences between participants may have been minimized.

Endurance performance is known to be an important parameter for taekwondo. Athletes exert significant effort during both training and competition. A match consists of three rounds of two minutes each, and athletes complete all their matches in one day. Therefore, taekwondo is directly related to endurance performance. The literature also includes studies highlighting the relationship between taekwondo and endurance (Aydemir et al., 2021; Ouergui et al., 2020; Song et al., 2015; Bridge et al., 2014; Fong & Ng, 2011). Tests measuring participants' anaerobic power and aerobic endurance were analyzed before and after the training programs.

For participants who performed plyometric training, post-test anaerobic power results improved significantly compared with pre-tests. Similarly, their fatigue index improved, but the difference was not statistically significant. Relative power and $MaxVO_2$ values showed significant improvements in favor of the post-test.

Participants who trained with taekwondo-specific resistance bands also showed significant post-test improvements in anaerobic power, fatigue index, relative power, and $MaxVO_2$ values.

For participants who only performed taekwondo training, significant improvements were found in anaerobic power, fatigue index, relative power, and $MaxVO_2$ values after training.

Between-group comparisons of anaerobic power revealed significant differences, with the greatest improvements observed in the plyometric group, followed by the resistance band group. Adding plyometric training to taekwondo programs appears to enhance anaerobic performance. Literature also reports positive effects of plyometric training on anaerobic power (Eyüboğlu et al., 2016)

Between-group comparisons of fatigue index also showed significant differences, favoring the plyometric group, followed by the resistance band group. The fatigue index reflects the difference in time between sprints, with higher scores indicating greater fatigue. The literature suggests that athletes with higher fatigue indices tend to have lower anaerobic power (Zagatto, 2009). Thus, improvements in the fatigue index for the plyometric group also indicate gains in anaerobic power, suggesting that including plyometric exercises in taekwondo training may reduce fatigue index and support anaerobic performance.

Relative power also showed significant differences between groups, with the greatest improvements in the plyometric group, followed by the resistance band group.

Similarly, $MaxVO_2$ values showed significant differences between groups, with results favoring the plyometric group. The literature indicates that plyometric exercises positively affect $MaxVO_2$ (Türkmen et al., 2010; Saygın et al., 2005). $MaxVO_2$ provides insight into aerobic endurance. In taekwondo, quick recovery between rounds and matches is crucial for sustaining high energy output. Barnett (2006) emphasized that $MaxVO_2$ capacity, which he defined as the ability to recover quickly after high-intensity exercise, is a key indicator of endurance performance.

The electronic vest kicking performance test is one of the study's most distinctive findings. The most frequently used competition techniques were identified by expert coaches. The analysis considered participants' within-group pre–post results and between-group outcomes.

For participants who performed plyometric training, significant post-test improvements were observed in both right and left palding chagi kicks. Similar significant improvements were noted in yopchagi and twisting palding chagi techniques.

Participants in the resistance band group also showed significant post-test improvements in right and left palding chagi, yopchagi, and twisting palding chagi kicks.

Control group participants demonstrated significant post-test improvements in right and left palding chagi and right yopchagi, while left yopchagi improvements were not significant. Significant gains were also seen in twisting palding chagi kicks.

Between-group analyses revealed significant differences for right and left palding chagi techniques, favoring the resistance band group (mean rank = 42.50), followed by the plyometric group (30.16) and the taekwondo-only group (25.84). Similarly, significant differences were found for right yopchagi, again favoring the resistance band group (42.59), then the plyometric group (31.75), and finally the control group (27.16).

No significant differences were found for left yopchagi, though mean ranks suggested that plyometric and resistance band groups improved more than the control group.

For right twisting palding chagi, significant differences favored the plyometric group (44.66), followed by the resistance band (37.73) and control groups (25.11). No significant differences were found for left twisting palding chagi, though mean ranks indicated greater gains in the plyometric group.

According to these results, performance improvements in electronic vest kicks were evident. Straight techniques such as palding chagi and yopchagi showed better outcomes in the resistance band group, while more athletic and complex techniques like twisting palding chagi favored plyometric training. Based on these findings, resistance band programs are recommended for direct, single-strike techniques, whereas plyometric

training may be more beneficial for athletic, jumping, and spinning techniques. Literature on this topic is scarce, which makes our study unique and a valuable contribution to understanding taekwondo performance.

This study demonstrates that plyometric and resistance band training yield distinct benefits for taekwondo athletes. Plyometric training primarily enhances power, speed, and explosive performance, while resistance band exercises improve balance and flexibility. These findings provide practical guidance for coaches to tailor training programs based on specific performance goals.

Given that the training methods providing the greatest contributions in the research groups were plyometric and taekwondo-specific resistance band training, it is recommended that athletes in the relevant age group incorporate these methods in addition to their regular taekwondo training.

To enhance taekwondo athletes' biomotor and physiological characteristics, it is recommended to include taekwondo-specific resistance band and plyometric training in preparatory-period programs.

It is recommended that these training methods also be integrated into the programs of athletes participating in development camps organized by the federation and in the youth preparatory squads of sports clubs, as they can contribute to biomotor and physiological performance.

As this research protocol was conducted with competitive taekwondo athletes in the youth category, it is recommended to replicate it with different age groups. The findings thus obtained could provide insights for both the literature and stakeholders (e.g., athletes, coaches).

Comparative studies are recommended involving athletes from other combat sports in which biomotor and physiological attributes are prominent (e.g., judo, karate), to enable comparison with our findings.

To observe the study in a competition context, it is recommended to relate the outcomes to actual competition results.

For demanding and athletic techniques, it is recommended to add plyometric training to taekwondo routines; for direct and explosive strikes, it is recommended to add taekwondo-specific resistance band training.

Finally, it is recommended to include delayed post-tests in future studies so that the results can be tracked over the long term.

Kısaltmalar / Abbreviations

SD	Standard deviation
X	Mean
SPSS	Statistical Package for the Social Sciences
p value	Probability value
t test	Independent Samples t Test F value F statistic
KBF	Kişisel Bilgi Formu
PI Form	Personal Information Form
N	Kişi Sayısı
Min	Minimum
Maks	Maksimum
Medyan	Ortanca Değer

Beyanlar / Declarations

Etik Onay ve Katılım Onayı / Ethics approval and consent to participate

Çalışmanın tasarımı, protokolü ve ilişkili riskler tüm katılımcılara ve yasal temsilcilerine açık bir şekilde iletilmiştir. Etik onay, Bayburt Üniversitesi Rektörlüğü Lisansüstü Eğitim Enstitüsü Müdürlüğü'nün 05.12.2022 tarihli ve E-83542712-050.99-106065 sayılı resmi yazısına istinaden alınmıştır. Çalışma, insan araştırmaları için Helsinki Bildirgesi'nin etik

ilkelerine uygun olarak yürütülmüştür. Tüm katılımcılardan ve reşit olmayanların yasal temsilcilerinden yazılı bilgilendirilmiş onam formları alınmıştır.

The study design, protocol, and associated risks were clearly communicated to all participants and their legal guardians. Ethical approval was obtained in accordance with the official letter from the Directorate of the Graduate Education Institute of Bayburt University Rectorate, dated 05.12.2022 and numbered E-83542712-050.99-106065. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki for human research. Written informed consent forms were obtained from all participants and the legal guardians of minors.

Veri Ve Materyal Erişilebilirliği / Availability of data and material

Bu çalışmanın bulgularını destekleyen veriler, makul talepler üzerine sorumlu yazardan temin edilebilir. Veri seti yalnızca akademik amaçlar için erişilebilir olacak ve verilerin herhangi bir kullanımı, orijinal çalışmayı referans gösterecek ve katılımcıların gizliliğini koruyacaktır.

The data that support the findings of this study are available from the corresponding author upon reasonable request. The dataset will be accessible only for academic purposes, and any use of the data will recognize the original study and maintain the confdentiality of the participants.

Çıkar Çatışması / Competing interests

Yazarlar, bu makalede sunulan çalışmayı etkileyebilecek herhangi bir çıkar çatışması veya kişisel ilişkiye sahip olmadıklarını beyan etmektedirler.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Yazar Katkıları / Authors' Contribution Statement

Çalışmanın tasarımı ve planlanması: BA.; Veri toplama, analizi veya yorumlanması:.B.A, Makalenin yazımı: B.A M.K.; Veri düzenleme, yöntem belirleme, yazım – özgün taslak, yazım – gözden geçirme ve düzenleme: M.K, Tüm yazarlar, makalenin önemli noktalarını eleştirel bir şekilde gözden geçirmiştir. Tüm yazarlar makalenin son halini onaylamıştır.

Study design and planning: B.A.; Data collection, analysis, and interpretation: B.A.; Manuscript writing: B.A., M.K.; Data organization, methodology development, writing – original draft, writing – review and editing: M.K. All authors critically reviewed the key aspects of the manuscript, and all authors have approved the final version of the manuscript.

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