INTERNATIONAL JOURNAL of IJSETS SPORT, EXERCISE & TRAINING SCIENCES

e-ISSN 2149-8229 **Volume** 10, **Issue** 4, 257–267, (2024) ***Original Article***

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

Effects of Static Stretching of Antagonist Muscles on Lower Extremity Power Output in Elite Female Volleyball Players

Gençer YARKIN[1], Alp Aslan UYSAL[2], Selda BEREKET YÜCEL[3], Mehmet Zeki ÖZKOL[4]

Abstract

Aim: This study aimed to investigate the effect of antagonist static stretching on lower-body peak power output in elite volleyball players.

Methods: Twenty-one elite female volleyball players (age: 23.95±5.04 years, height: 181.90±7.54 cm, mass: 70.96±8.38 kg) were randomly divided into two groups: 1) antagonist static stretching group and 2) dynamic stretching group. After implementing the stretching protocols, peak power output was assessed by performing loaded squat jumps using three different loads: 20%, 40%, and 60% of one-repetition maximum. Forty-eight hours later, on the second testing day, participants in the dynamic stretching group and antagonist static stretching group switched groups and underwent the same procedure.

Results: Peak power output obtained at 20% of one repetition maximum in dynamic stretching group was significantly greater than the peak power output at the same load in the antagonist static stretching group (p<0,05); no significant difference was found at the other equal loads between stretching groups (p>0,05). Peak power output values at three different exercise loads within each group were analyzed: in dynamic stretching group, peak power output was significantly greater at 20% compared to 60% of one repetition maximum (p<0,05), and at 40% compared to 60% of one repetition maximum (p<0,05). In antagonist static stretching group, peak power output was significantly greater at 20% compared to 60% of one repetition maximum (p<0,05), and at 40% compared to 60% of the one repetition maximum (p<0,05).

Conclusion: Antagonist static stretching did not produce any beneficial effects in elite female volleyball players when compared to dynamic stretching.

Keywords

Volleyball,
Peak power output,
Static stretching,
Antagonist static stretching.

Article Info

Received: 03.11.2024
Accepted: 19.12.2024
Online Published: 31.12.2024

DOI:10.18826/useeabd.1578359

Kadın Voleybolcularda Antagonist Kasa Yapılan Statik Germenin Alt Ekstremite Güç Çıktısına Etkisi

Özet

Amaç: Bu çalışmanın amacı, elit voleybol oyuncularında antagonist statik germe uygulamasının alt vücut zirve güç çıktısı üzerindeki etkisini incelemektir.

Yöntem: Çalışmaya 21 elit kadın voleybolcu (yaş: 23,95±5,04 yıl, boy: 181,90±7,54 cm, vücut kütlesi: 70,96±8,38 kg) katılmıştır. Katılımcılar, birinci test gününde rastgele iki gruba dağıtılmıştır: 1) antagonist statik germe grubu ve 2) dinamik germe grubu. Germe protokolleri uygulandıktan sonra zirve güç çıktısı, %20, %40 ve %60 bir tekrar maksimum ağırlık ile yapılan skuat sıçramaları sırasında değerlendirilmiştir. 48 saat sonra, ikinci test gününde, dinamik germe grubu ve antagonist statik germe grubu katılımcıları grup değiştirmiştir ve aynı prosedür uygulanmıştır.

Bulgular: Dinamik germe grubunda bir tekrar maksimumun %20'sinde elde edilen zirve güç çıktısı, antagonist statik germe grubunda aynı yükte elde edilen zirve güç çıktısından anlamlı derecede yüksektir (p<0,05). Diğer eşit yüklerde gruplar arasında zirve güç çıktısında anlamlı bir fark bulunmamıştır (p>0,05). Her iki germe grubunda üç farklı yük altında üretilen zirve güç çıktısı değerleri analiz edilmiştir. Dinamik germe grubunda zirve güç çıktısı, bir tekrar maksimumun %20'sinde, bir tekrar maksimumun %60'ına kıyasla anlamlı derecede daha yüksek bulunmuştur (p<0,05); ek olarak, bir tekrar maksimumun %40'ında zirve güç çıktısı, bir tekrar maksimumun %60'ına kıyasla anlamlı derecede daha yüksek bulunmuştur (p<0,05). Antagonist statik germe grubunda ise, zirve güç çıktısı, bir tekrar maksimumun %20'sinde, bir tekrar maksimumun %60'ına kıyasla anlamlı derecede daha yüksek bulunmuştur (p<0,05); bir tekrar maksimumun %40'ında ise bir tekrar maksimumun %60'ına kıyasla anlamlı derecede daha yüksek bulunmuştur (p<0,05).

Sonuç: Antagonist statik germe, dinamik germe ile karşılaştırıldığında elit kadın voleybol oyuncularında herhangi bir faydalı etki üretmemiştir.

Anahtar Kelimeler

Voleybol,
Zirve güç çıktısı,
Statik germe,
Antagonist statik germe.

Yayın Bilgisi

Gönderi Tarihi: 03.11.2024
Kabul Tarihi: 19.12.2024
Online Yayın Tarihi: 31.12.2024

DOI:10.18826/useeabd.1578359

[1] ***Corresponsible Author:*** Marmara University, Institute of Health Sciences, genceryarkin@gmail.com
[2] Marmara University, Institute of Health Sciences, alpaslan-89@hotmail.com
[3] Marmara University, Institute of Health Sciences, selda.yucel@marmara.edu.tr
[4] Ege University, School of Physical Education and Sports, zeki.ozkol@ege.edu.tr

INTRODUCTION

Volleyball is an intermittent sport characterized by short and high-intensity explosive movements (VanHeest, 2003). Success is not solely reliant on mastering volleyball technical abilities; possessing superior jumping skills is imperative to secure an edge over the opposing team (Ziv and Lidor, 2020). In elite women's volleyball, the frequency of vertical jumps executed within a game demonstrates substantial variability contingent upon factors encompassing the player's positional role, the duration of active play, and the dynamics inherent in the game. An elite player can perform more than 100 jumps in a single match (Kerkoski et al., 2019). While the frequency of jumps during matches may fluctuate, there is a strong relationship between vertical jump performance and lower-body power production during triple extension (Chang et al., 2015; Kons et al., 2018). The lower-body peak power output during vertical jumps is influenced by various key parameters. Among these, muscular strength plays a pivotal role, especially in muscles such as quadriceps, hamstrings, and glutes (Bredeweg, 2003; Cormie et al., 2007; Kons et al., 2018; Montalvo, 2021). Maximizing force development during the push-off phase, along with adequate flexibility in the lower body, significantly affects the power generated (Montalvo, 2021).

Static stretching exercises are employed to enhance athlete flexibility and mitigate injury risks during the execution of high-power movements (Behm et al., 2016; Chaabene et al., 2019; Smith, 1994). However, previous research has demonstrated the negative effects of static stretching of the agonist muscles on strength and power production (Behm et al., 2021; Cramer et al., 2005; Jeffreys, 2008). Some of the studies revealed that prolonged static stretching decreased muscle activation (Cramer et al., 2005; Ryan et al., 2014) while others found no significant change in muscle activation but suggested that the loss of strength resulted from altered mechanical factors of the muscle (Herda et al., 2008; Sandberg et al., 2012). The negative impact of static stretching on muscle contraction raises the question of whether antagonist static stretching could contribute to agonist performance; reducing antagonist co-contraction theoretically enhances agonist power output potential by requiring less work to perform the same task (Ford et al., 2008). Recent research examined the effects of static stretching of the antagonist muscles on lower-body power output (Cè et al., 2021; Cogley et al., 2021; Montalvo, 2021; Sandberg et al., 2012; Serefoglu et al., 2017; Wakefield and Cottrell, 2015); nevertheless, there was no study within our knowledge that focused on elite volleyball players related to this topic.

The squat jump, involving the aforementioned crucial muscle groups for vertical propulsion, is a fundamental exercise employed by volleyball athletic performance coaches to assess and monitor the lower-body power output during triple extension (Soriano et al., 2015). The impact of static stretching applied to the antagonist muscles on peak power output during loaded squat jumps, particularly within the context of elite female volleyball players, remains a topic that requires further elucidation. The aim of this study is to investigate the impact of static stretching of antagonist muscles on the lower-body peak power output during loaded squat jumps in elite female volleyball players. It was hypothesized that applying static stretching to antagonist muscles would significantly increase peak power output during loaded squat jumps in elite female volleyball players.

METHOD

Model of the research

This study employed a crossover design to investigate the effect of static stretching on antagonist muscles on lower-body peak power output during the loaded squat jump exercise in elite female volleyball players. The independent variables of the study included the types of stretching exercises, and the dependent variables included the peak power output values during squat jumps with 20%, 40%, and 60% of one-repetition maximum loads.

Study group of the research

This study recruited 21 elite female volleyball players (age: 23.95 ± 5.04 years; height: 181.90 ± 7.54 cm; body mass: 70.96 ± 8.38 kg, body fat: 19.26%, one-repetition maximum squat: 117.62 kg) who have competed at national and international levels and currently play in the Turkish Professional Volleyball Super League. Participants were professional volleyball players of the Galatasaray Sports Club between the ages of 18-35; had a minimum training experience of five years and had at least three years of experience in strength training. All participants possessed a doctor's approval for engaging in sports activities, with no restrictions on their sports licenses. The study was conducted in compliance with the Declaration of Helsinki and approved by the Ege University Faculty of Medicine Research Ethics Board.

Data collection tools of the research

On the first day, the participants signed a consent form indicating their voluntary participation in the study and acknowledging an understanding of its purpose and content. Anthropometric measurements, including height, sitting height, biacromial width, body weight, and body fat percentage, were recorded. One-repetition maximum loads in the squat exercise were then determined. On the second day, a familiarization session was conducted. The third and fourth days were the test days. The testing sessions were conducted at the same time of the day from 10 AM to noon. The temperature of the testing center was set at 20 degrees Celsius during each testing day. After the first and second days, a 24-hour break was given, followed by a 48-hour break between the third and fourth days.

Anthropometric tests: Heights of the participants were measured using a stadiometer. Sitting height was measured while the participants were seated with their knees at a 90° angle. The biacromial width was measured using an anthropometer, and the distance between the two acromial ends was recorded while each participant's back was turned in a standing upright position. Body weight, body mass index and body fat percentage were measured using a Tanita Bioelectrical Impedance device (Tanita MC980 MA; Tanita C.O., Tokyo, Japan).

One repetition maximum test for squat: One-repetition maximum loads at the squat exercise were measured using a Smith Machine (Technogym ELEMENT+ MULTIPOWER, Technogym C.O., New Jersey, USA). After completing a general warm-up, which included 10-15 minutes of running and dynamic stretches, the participants' one-repetition maximum loads were determined using the prescribed protocol outlined by the National Strength and Conditioning Association (Sheppard and Triplett, 2016). First, participants were instructed to choose a light load, allowing for effortless completion of five to 10 repetitions. Following this initial set, a one-minute rest interval was provided. Subsequently, the loads were estimated to enable participants to perform three to five repetitions, achieved by either adding 14-18 kg or increasing by 10% to 20%. A two-minute rest period was provided before estimating modest loads that allowed participants to complete two or three repetitions, involving a similar adjustment of 14-18 kg or a 10% to 20% increase. Following this, two to four-minute rest period was provided. The subsequent step involved incrementing the weight by 14-18 kg or 10% to 20%, prompting participants to attempt a maximal lift for a single repetition. In cases of unsuccessful attempts, an additional rest period of two to four minutes was provided, followed by a repetition attempt with a 5-10% reduced weight if needed.

Stretching protocols: In this study, two stretching protocols were implemented. The protocols were divided into i) dynamic stretching for both the agonist and the antagonist muscles and ii) antagonist static streching, in addition to dynamic stretching for the agonist muscles used in the squat jump exercise. The stretching protocols were implemented following a five-minute aerobic run. In the antagonist static stretching protocol, static stretching was applied to the hip flexor, knee flexor, and dorsiflexor muscles. Each static stretching exercise was applied in three sets for each leg, alternating between the left and right legs. Each set lasted for 30 seconds, followed by a 10-second rest, with participants alternating legs in each set. Dynamic stretching exercises involved two sets of 10 reps for each leg, incorporating a full range of motion dynamic movements stated in Table 1. No rest period was provided between dynamic stretching sets; participants alternated legs after completing each set. Static stretching exercises for the hamstring and tibialis anterior muscles were performed up to the pain threshold of the participants with an external resistance provided by an expert physiotherapist; static stretching exercise for the hip flexor muscles was performed by the athletes following the verbal cues of the physiotherapist without receiving external physical assistance (Figure 1). The sequence of the stretching protocol by muscle group is as follows: 1) hip flexors, 2) hip extensors, 3) hip adductors, 4) hip abductors, 5) knee extensors, 6) knee flexors, 7) dorsi flexors, 8) plantar flexors.

Figure 1. Antagonist static stretching of tibialis anterior, hamstring, iliopsoas

The stretching exercises used in the dynamic stretching and antagonist static stretching protocols are listed in Table 1.

Table 1. Types of stretching exercises

Muscle Groups	Dynamic Stretching Exercises	DS Protocol	ASS Protocol
Hip Flexors	Dynamic half-kneeling hip flexor stretch	10 reps of 2 sets for both sides	3x30 seconds of static stretching only
Hip Extensors	Dynamic hip flexion in a supine lying position	10 reps of 2 sets for both sides	Same as DS protocol
Hip Adductors	Dynamic hip abduction while standing with support	10 reps of 2 sets for both sides	Same as DS protocol
Hip Abductors	Dynamic hip adduction while standing with support	10 reps of 2 sets for both sides	Same as DS protocol
Knee Extensors	Dynamic knee flexion in a prone lying position	10 reps of 2 sets for both sides	Same as DS protocol
Knee Flexors	Dynamic hamstring stretch in a supine lying position	10 reps of 2 sets for both sides	3x30 seconds of static stretching only
Dorsi Flexors	Dynamic plantar flexion in a sitting position with extended knees	10 reps of 2 sets for both sides	3x30 seconds of static stretching only
Plantar Flexors	Dynamic dorsiflexion in a sitting position with extended knees	10 reps of 2 sets for both sides	Same as DS protocol

DS Protocol = dynamic stretching protocol; ASS Protocol = antagonist static stretching protocol

Measurement of peak power output during squat jump exercise: The measurements were conducted using a Smith Machine because the utilization of either free weights or a Smith Machine did not significantly affect the measurement outcomes (Dugan et al., 2004), and the latter was considered safer. Squat jumps with different loads were performed in a randomized order. A force platform (ForceDecks Model FDLITE., NMP Technologies Ltd., London, United Kingdom) was used for the peak power output measurement; changes in the ground reaction force were measured, and data were obtained in watts. The measurement steps were as follows.

Preparation phase: The participant stepped onto the force platform placed under the Smith Machine bar. The feet were spaced at a distance equal to the measured biacromial width. The toes were turned slightly outward. The bar was positioned immediately above the posterior deltoid muscles, just below the seventh cervical vertebra. The vertical alignment of the bar was positioned at the midpoint of the feet.

Eccentric phase: After the participant was positioned under the bar, two verbal cues were provided. The first verbal cue signaled the eccentric phase, and the second cue indicated the start of the concentric phase. In response to the first cue for the eccentric phase, the knees were flexed until they reached 90°. To ensure standardization of the knee angle during the squat, the hip height and position of the toes on the force platform were marked for each participant when their knees reached 90° flexion.

Various boxes and mats at different heights were used to standardize hip height, and the positions of the toes were marked using a ruler (Figure 2).

Concentric phase: After the second verbal cue, the jump movement was executed with rapid simultaneous extension of the ankle, knee, and hip. Throughout the exercise, the force platform was connected to a computer to automatically process information regarding the movement pattern and load through its sensors. For example, it could detect whether the movement was a dynamic jump instead of a squat jump.

Figure 2: Standardization of the knee angle

Loaded squat jump testing: The loaded squat jump tests were completed over two days, with a 48-hour rest between sessions. The participants were instructed to abstain from food for up to 3 hours before the test and ensure adequate fluid intake. The participant group, consisting of 21 athletes, was randomly divided into two groups with single-blind randomization: the dynamic stretching group and the antagonist static stretching group. In the dynamic stretching group, dynamic stretching was applied to both the agonist and antagonist muscles, while in the antagonist static stretching group, dynamic stretching was applied to agonist muscles and static stretching to antagonist muscles used in the squat jump exercise. Following the warm-up and stretching protocols, individuals within each group performed loaded squat jump exercises with single repetitions at 20-40% and 60% of their one-repetition maximum loads. Two sets for each load were applied, totaling six sets performed in a randomized order. A two-minute rest was given between each set. The average peak power output of the two sets for each load was calculated. Between the stretching protocol and the squat jump testing, the researcher did not plan a fixed rest interval; participants moved to loaded squat jumps immediately after the stretching protocol. This decision aimed to observe the effects of static stretching by mitigating the time delay effect.

48 hours later, on the second testing day, participants in the dynamic stretching group and antagonist static stretching group switched and followed the same procedure.

Data analysis of the research

SPSS 22 for Windows XP was used for the statistical analyses. The data was verified for normality using the Shapiro-Wilk test. Absolute reliability was assessed with coefficient of variation, and relative reliability was evaluated with intraclass correlation coefficients. The calculation of the intraclass correlation coefficients followed the guidelines outlined by Koo et al. (2016) and was interpreted based on the subsequent standards: below 0.50, considered poor; within the range of 0.50–0.74, considered moderate; standing between 0.75 and 0.90, considered good; and equal to or exceeding 0.90, considered excellent. The peak power output values obtained at the same exercise loads after different stretching protocols, and the peak power output values obtained at three different exercise loads after the same stretching protocol were assessed using ANOVA (post-hoc LSD method) with repeated measurements. A significance level of $p \leq 0.05$ was accepted for all analyses.

FINDINGS

The data was normally distributed. Mean test results and reliability data are shown in Table 2.

Table 2. Peak power output of both groups during squat jumps with different loads

Squat Jump Load	Stretching Group	Mean ± SD (Watts)	CV (%)	ICC (95% CI)
20% of 1RM	DSG	2830 ± 378	13.4	0.94 (0.85-0.97)
	ASSG	2748 ± 414	15.1	0.95 (0.87-0.98)
40% of 1RM	DSG	2803 ± 389	13.9	0.94 (0.87-0.98)
	ASSG	2761 ± 474	17.2	0.92 (0.60-0.98)
60% of 1RM	DSG	2699 ± 411	15.2	0.87 (0.72-0.95)
	ASSG	2627 ± 393	15	0.92 (0.71-0.97)

1RM = one repetition maximum; DSG = dynamic stretching group; ASSG = antagonist static stretching group; SD = standard deviation; CV = coefficient of variation; ICC = intra-class correlation coefficient; CI = confidence interval

The absolute and relative reliability values were found to be within acceptable ranges. The peak power output values produced at the same exercise loads after different stretching protocols were analyzed. Pairwise comparisons at the same exercise loads after different stretching protocols are presented in Table 3.

Table 3. Pairwise comparisons at the same exercise load after different stretching protocols

Measure	Stretching Group (I)	Stretching Group (J)	Mean Difference (I-J)	SE	Sig.^{b}	95% CI for Difference Lower Bound	95% CI for Difference Upper Bound
20% of 1RM	DSG	ASSG	82.524*	35.71	0.03	8.043	157.004
	ASSG	DSG	-82.524*	35.71	0.03	-157.004	-8.043
40% of 1RM	DSG	ASSG	42.571	64.48	0.52	-91.925	177.068
	ASSG	DSG	-42.571	64.48	0.52	-177.068	91.925
60% of 1RM	DSG	ASSG	72	44.32	0.12	-20.449	164.449
	ASSG	DSG	-72	44.32	0.12	-164.449	20.449

*1RM = one repetition maximum; DSG = dynamic stretching group; ASSG = antagonist static stretching group; SE = standard error; sig^b = significance value; CI = confidence interval; ^{b} = adjustment for multiple comparisons: least significance difference; *p<0.05*

Dynamic stretching resulted in significantly higher peak power output values than antagonist static stretching, but significant effect was observed only in squat jumps performed with 20% of the one-repetition maximum load ($p=0.032$). The peak power output values produced at three different exercise loads after the same stretching protocol were analyzed. Pairwise comparisons at three different exercise loads after the same stretching protocol are presented in Table 4.

Table 4. Pairwise comparisons at three different exercise loads after the same stretching protocol

Measure	Exercise Load (I)	Exercise Load (J)	Mean Difference (I-J)	SE	Sig.[b]	95% CI for Difference Lower Bound	95% CI for Difference Upper Bound
DSG	20% of 1RM	40% of 1RM	27.095	38	0.49	-52.377	106.568
		60% of 1RM	131.238*	48	0.01	30.791	231.685
	40% of 1RM	20% of 1RM	-27.095	38	0.49	-106.568	52.377
		60% of 1RM	104.143*	40	0.02	20.611	187.675
	60% of 1RM	20% of 1RM	-131.238*	48	0.01	-231.685	-30.791
		40% of 1RM	-104.143*	40	0.02	-187.675	-20.611
ASSG	20% of 1RM	40% of 1RM	-12.857	42	0.77	-101.352	75.638
		60% of 1RM	120.714*	51	0.03	14.179	227.25
	40% of 1RM	20% of 1RM	12.857	42	0.77	-75.638	101.352
		60% of 1RM	133.571*	47	0.01	35.255	231.888
	60% of 1RM	20% of 1RM	-120.714*	51	0.03	-227.25	-14.179
		40% of 1RM	-133.571*	47	0.01	-231.888	-35.255

*DSG = dynamic stretching group; ASSG = antagonist static stretching group; 1RM = one repetition maximum; SE = standard error; sig[b] = significance value; CI = confidence interval; [b] = adjustment for multiple comparisons: least significance difference; *p<0.05*

In the dynamic stretching group, significant differences in peak power outputs were between 20% and 60% of the one-repetition maximum (p=0.013) and between 40% and 60% of the one-repetition maximum loads (p=0.017); the peak power output values obtained at the respective one-repetition maximum loads were sorted in a descending order as follows: 20% > 40% > 60% of one-repetition maximum. In the antagonist static stretching group, significant differences in peak power outputs were between 20% and 60% of the one-repetition maximum (p=0.028) and between 40% and 60% of the one-repetition maximum loads (p=0.01); the peak power output values gathered at the respective one-repetition maximum loads were ranked in a decreasing order as follows: 40% > 20% > 60% of one-repetition maximum.

DISCUSSION

There is no consensus among researchers regarding the effects of static stretching of the antagonist muscle on the agonist muscle activity (Cè et al., 2021; Cogley et al., 2021; Montalvo, 2021; Sandberg et al., 2012; Serefoglu et al., 2017; Wakefield and Cottrell, 2015). Research has been conducted on the effects of antagonist static stretching on isokinetic strength (Cogley et al., 2021; Montalvo, 2021; Sandberg et al., 2012; Serefoglu et al., 2017), muscle activation (Cè et al., 2021; Montalvo, 2021; Sandberg et al., 2012; Serefoglu et al., 2017) and jumping performance (Montalvo, 2021; Sandberg et al., 2012; Wakefield and Cottrell, 2015). In the literature, no study within our knowledge focused on elite volleyball players related to the effects of antagonist static stretching on athletic performance. This study aimed to investigate the impact of static stretching of antagonist muscles on the lower-body peak power output during loaded squat jumps in elite female volleyball players.

Research suggests that a decrease in the level of antagonist muscle co-activation enhances the strength and power of the agonist muscle (Cormie et al., 2011). In this study, peak power output during the squat jump with 20% of the one-repetition maximum load was significantly higher in the dynamic stretching group than that in the antagonist static stretching group. No significant differences between the groups were observed in peak power output with 40% and 60% of one-repetition maximum loads. According to these results, static stretching of the antagonist muscles does not result in higher squat jump performance in elite female volleyball players. However, muscle activation was not measured in this study; therefore, the role of muscle activation cannot be discussed to our findings.

Several researchers investigated the impact of manipulations on antagonist muscles in lower-body movement performance (Cè et al., 2021; Cogley et al., 2021; Montalvo, 2021; Sandberg et al., 2012; Serefoglu et al., 2017; Wakefield and Cottrell, 2015) In the research conducted by Serefoglu et al. (2017), neither dynamic nor static stretching of antagonist muscles produced a significant change in peak torque and EMG activity in knee extension/flexion isokinetic test results. In the study of Cè et al. (2021), passive static stretching applied to the plantar flexors did not alter the neuromuscular functions of the antagonist muscle, tibialis anterior, despite the demonstrated effectiveness of the stretching maneuver on the plantar flexors. Sandberg et al. (2012) reported that vertical jump and torque production increased with antagonist static stretching when applied before movement. In Wakefield and Cottrell's (2015) research, static stretching applied to antagonist muscles resulted in a significant increase in vertical jump height. In the study by Cogley et al. (2021), participants who applied dynamic stretching followed by antagonist muscle static stretching demonstrated significant improvements in peak torque at both $60°.s^{-1}$ and $300°.s^{-1}$. Additionally, they experienced a significant reduction in the time to peak torque and an increase in average power at $60°.\ s^{-1}$. Montalvo (2021) reported that the combination of dynamic stretching of the agonist and static stretching of the antagonist muscles resulted in significantly improved isokinetic strength and vertical jump performance. However, the observed improvements did not show significant differences when compared to the outcomes of dynamic stretching of both the agonist and antagonist muscles. Montalvo (2021) emphasized the need for future studies involving athletes from different sporting populations to further explore this topic.

Unlike the aforementioned studies, this study was conducted on elite athletes who compete at the national and international levels. The body fat percentages of these athletes were lower than those of amateur volleyball players (Fields et al., 2018). The one-repetition maximum squat loads of these athletes exceeded the NSCA 90th percentile value significantly (Harman and Garhammer, 2008). Elite athletes have different co-activation levels than non-elite athletes; co-activation tends to increase while learning a new skill and decreases as learning progresses (Simsek and Ertan, 2014). Therefore, the participants' elite status may have influenced the results due to the learning-coactivation relationship, as they were already very familiar with the squat jump exercise before this study.

The squat jump exercise incorporates a triple extension mechanism involving ankle, knee, and hip extensions. During knee extension, the antagonist of the quadriceps muscle is the hamstring (Pessoa et al., 2023). However, the hamstring is a biarticular muscle that assists in hip extension (Schoenfeld, 2010). In this study, the hamstring muscle is one of the muscles subjected to static stretching as an antagonist; therefore, static stretching of the hamstring muscles may not have altered the amount of power generated in the triple extension mechanism.

Co-activation is activating the antagonist muscles that act in the opposite direction of the force produced during joint movement (Latash, 2018). For efficient movement, agonist activation should be supported by increased synergistic activity and reduced co-activation of antagonists (Cormie et al., 2011). However, co-activation, particularly during ballistic movements, regulates joint stability (Aagaard, 2011). The co-activation pattern of agonist and antagonist pairs is governed by the central nervous system through the "common drive" mechanism (Simsek and Ertan, 2014). Static stretching may inhibit antagonist muscles (Miranda et al., 2015); consequently, the extent of inhibition in antagonist muscles may cause transmission of inhibitory signals to agonist muscles through a common drive mechanism, potentially maintaining joint stability.

The squat jump has been suggested as an ideal exercise for maximizing lower-body peak power in the athletic population (Cormie, 2007; Thompson, 2023). In this study, no significant differences in peak power output were observed between 20% and 40% of the one-repetition maximum loads. The 60% one-repetition maximum load resulted in the lowest peak power performance. There are various results in the literature regarding the optimal load for squat jumps. Some studies state that peak power output is achieved with no external load (Cormie et al., 2008), while others report no significant difference between 10% and 20% of one-repetition maximum loads (Turner et al., 2015), and others suggest that optimal performance occurs with loads below 30% of one-repetition maximum (Soriano et al., 2015). This study provides supporting evidence that peak power output in the squat jump occurs at low loads, which was below 40% of the one-repetition maximum in our study.

Finally, '3x30 seconds' of static stretching for the antagonist muscles was applied to each leg in the antagonist static stretching group; 10 s of rest was given between sets. The total number of static stretching sets per participant was 18, calculated by summing the sets for each leg in every static stretching exercise; this created a static period of 12 minutes. In addition, participants in the antagonist static stretching group applied dynamic stretching exercises for other muscle groups stated in Table 1, which added 10 more sets of 10 reps for each leg, 20 more sets of 10 reps in total. The total stretching time in the antagonist static stretching protocol lasted around 20 minutes, which may negatively affected the squat jump performances because of the long duration between the warm up which was done before the stretching protocols and the squat jumps.

CONCLUSION

In this study, i) the already low levels of co-activation in highly trained elite athletes, ii) the hamstring muscle having a different role than anticipated during the concentric phase of the squat jump, iii) the effect of the central nervous system reducing agonist muscle activation through the common drive mechanism, and iv) the long duration of the antagonist static stretching protocol may be among the reasons why static stretching applied to the antagonist did not positively affect lower extremity peak power performance. Since antagonist static stretching did not produce any beneficial effects on lower body peak power output in elite female volleyball players compared to dynamic stretching, strength and conditioning coaches need not incorporate antagonist static stretching into training programs or pre-game routines for this population.

Ethical Approval Permission Information
Ethics Committee: Ege Üniversitesi, Tıbbi Araştırmalar Etik Kurulu
Division / Protocol No: 19-5T/36

REFERENCES

Aagaard, P. (2011). Neural adaptations to resistance exercise. In M. Cardinale, R. Newton, & K. Nosaka (Eds.), *Strength and Conditioning: Biological Principles and Practical Applications*. Hoboken, NJ: Wiley-Blackwell.

Behm, D. G., Alizadeh, S., Drury, B., Granacher, U., & Moran, J. (2021). Non-local acute stretching effects on strength performance in healthy young adults. *European Journal of Applied Physiology*, *121*(6), 1517–1529. https://doi.org/10.1007/s00421-021-04657-w

Behm, D. G., Blazevich, A. J., Kay, A. D., & McHugh, M. (2016). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: A systematic review. *Applied Physiology, Nutrition, and Metabolism*, *41*(1), 1–11. https://doi.org/10.1139/apnm-2015-0235

Behm, D. G., Kay, A. D., Trajano, G. S., & Blazevich, A. J. (2021). Mechanisms underlying performance impairments following prolonged static stretching without a comprehensive warm-up. *European Journal of Applied Physiology*, *121*(1), 67–94. https://doi.org/10.1007/s00421-020-04538-8

Bredeweg, S. (2003). The elite volleyball athlete. In J. C. Reeser & R. Bahr (Eds.), *Volleyball: Handbook of Sports Medicine and Science* (2nd ed.). Hoboken, NJ: Blackwell Science Ltd.

Cè, E., Coratella, G., Doria, C., Rampichini, S., Borrelli, M., Longo, S., & Esposito, F. (2021). No effect of passive stretching on neuromuscular function and maximum force-generating capacity in the antagonist muscle. *European Journal of Applied Physiology*, *121*(7), 1955–1965. https://doi.org/10.1007/s00421-021-04646-z

Chaabene, H., Behm, D. G., Negra, Y., & Granacher, U. (2019). Acute effects of static stretching on muscle strength and power: an attempt to clarify previous caveats. *Frontiers in Physiology*, *10*, 1468. https://doi.org/10.3389/fphys.2019.01468

Chang, E., Norcross, M. F., Johnson, S. T., Kitagawa, T., & Hoffman, M. (2015). Relationships between explosive and maximal triple extensor muscle performance and vertical jump height. *Journal of Strength and Conditioning Research*, *29*(2), 545–551. https://doi.org/10.1519/JSC.0000000000000652

Cogley, D., Byrne, P., Halstead, J., & Coyle, C. (2021). Responses to a combined dynamic stretching and antagonist static stretching warm-up protocol on isokinetic leg extension performance. *Sports Biomechanics*, 1–16. Advance online publication. https://doi.org/10.1080/14763141.2021.1944290

Cormie, P., McBride, J. M., & McCaulley, G. O. (2008). Power-time, force-time, and velocity-time curve analysis during the jump squat: Impact of load. *Journal of Applied Biomechanics*, *24*(2), 112–120. https://doi.org/10.1123/jab.24.2.112

Cormie, P., McCaulley, G. O., Triplett, N. T., & McBride, J. M. (2007). Optimal loading for maximal power output during lower-body resistance exercises. *Medicine and Science in Sports and Exercise*, *39*(2), 340–349. https://doi.org/10.1249/01.mss.0000246993.71599.bf

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power: Part 1--biological basis of maximal power production. *Sports Medicine*, *41*(1), 17–38. https://doi.org/10.2165/11537690-000000000-00000

Cramer, J. T., Housh, T. J., Weir, J. P., Johnson, G. O., Coburn, J. W., & Beck, T. W. (2005). The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. *European Journal of Applied Physiology*, *93*(5-6), 530–539. https://doi.org/10.1007/s00421-004-1199-x

Dugan, E. L., Doyle, T. L., Humphries, B., Hasson, C. J., & Newton, R. U. (2004). Determining the optimal load for jump squats: A review of methods and calculations. *Journal of Strength and Conditioning Research*, *18*(3), 668–674.

Fields, J. B., Merrigan, J. J., White, J. B., & Jones, M. T. (2018). Body composition variables by sport and sport-position in elite collegiate athletes. *Journal of Strength and Conditioning Research*, *32*(11), 3153–3159. https://doi.org/10.1519/JSC.0000000000002865

Ford, K. R., Van den Bogert, J., Myer, G. D., Shapiro, R., & Hewett, T. E. (2008). The effects of age and skill level on knee musculature co-contraction during functional activities: A systematic review. *British Journal of Sports Medicine*, *42*(7), 561–566. https://doi.org/10.1136/bjsm.2007.044883

Harman, E., & Garhammer, J. P. (2008). Administration, scoring, and interpretation of selected tests. In T.R. Baechle & R.W. Earle (Eds.), *Essentials of Strength Training and Conditioning* (3rd ed.). Champaign, IL: Human Kinetics.

Herda, T. J., Cramer, J. T., Ryan, E. D., McHugh, M. P., & Stout, J. R. (2008). Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. *Journal of Strength and Conditioning Research*, *22*(3), 809–817. https://doi.org/10.1519/JSC.0b013e31816a82ec

Jeffreys, I. (2008). Warm-up and stretching. In T.R. Baechle & R.W. Earle (Eds.), *Essentials of Strength Training and Conditioning* (3rd ed.). Champaign, IL: Human Kinetics.

Kerkoski, M. J., Da Silva, L. H. M., Hodeck, A., Tuchel, J., & Hente, L. (2019). Jumping in the Brazilian women's volleyball "B" super-league. *Proceedings of the International Seminar of Physical Education, Leisure and Health,* Portugal, 14(4proc), 1453-1455. https://doi.org/10.14198/jhse.2019.14.Proc4.82

Kons, R. L., Ache-Dias, J., Detanico, D., Barth, J., & Dal Pupo, J. (2018). Is vertical jump height an indicator of athletes' power output in different sport modalities?. *Journal of Strength and Conditioning Research*, *32*(3), 708–715. https://doi.org/10.1519/JSC.0000000000001817

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Kushner, R. F. (1992). Bioelectrical impedance analysis: A review of principles and applications. *Journal of the American College of Nutrition*, *11*(2), 199–209.

Latash, M. L. (2018). Muscle coactivation: definitions, mechanisms, and functions. *Journal of Neurophysiology*, *120*(1), 88–104. https://doi.org/10.1152/jn.00084.2018

Miranda, H., Maia, M.de. F., Paz, G. A., & Costa, P. B. (2015). Acute effects of antagonist static stretching in the inter-set rest period on repetition performance and muscle activation. *Research in Sports Medicine*, *23*(1), 37–50. https://doi.org/10.1080/15438627.2014.975812

Montalvo, S. (2021). *Effects of different stretching modalities on the antagonist and agonist muscles on isokinetic strength and vertical jump performance*. Doctoral dissertation. The University of Texas at El Paso. Open Access Theses & Dissertations. https://scholarworks.utep.edu/open_etd/3299

Pessoa, D., Penfold, H., Pegado, S., Gonçalves, M., Brandão, J., Willardson, J., & Miranda, H. (2023). Effect of static stretching on agonists, antagonists, and agonist-antagonist combination on total training volume. *International Journal of Exercise Science*, *16*(4), 665–675.

Ryan, E. D., Herda, T. J., Costa, P. B., Herda, A. A., & Cramer, J. T. (2014). Acute effects of passive stretching of the plantarflexor muscles on neuromuscular function: the influence of age. *Age*, *36*(4). https://doi.org/10.1007/s11357-014-9672-x

Sandberg, J. B., Wagner, D. R., Willardson, J. M., & Smith, G. A. (2012). Acute effects of antagonist stretching on jump height, torque, and electromyography of agonist musculature. *Journal of Strength and Conditioning Research*, *26*(5), 1249–1256. https://doi.org/10.1519/JSC.0b013e31824f2399

Schoenfeld, B. J. (2010). Squatting kinematics and kinetics and their application to exercise performance. *Journal of Strength and Conditioning Research*, *24*(12), 3497–3506. https://doi.org/10.1519/JSC.0b013e3181bac2d7

Serefoglu, A., Sekir, U., Gür, H., & Akova, B. (2017). Effects of static and dynamic stretching on the isokinetic peak torques and electromyographic activities of the antagonist muscles. *Journal of Sports Science & Medicine*, *16*(1), 6–13.

Sheppard, J. M., & Triplett, N. T. (2016). Program design in resistance training. In G. G. Haff & N. T. Triplett (Eds.), *Essentials of Strength Training and Conditioning* (4th ed.). Champaign, IL: Human Kinetics.

Simsek, D., & Ertan, H. (2014). Motor beceri öğreniminde kas ko-aktivasyon ve rekürrent inhibisyon aktivitesinin fonksiyonel önemi [Functional Significance of Muscle Co-activation and Recurrent Inhibition Activity at Motor Skill Learning]. SPORMETRE Beden Eğitimi ve Spor Bilimleri Dergisi, 12(1), 51-57. https://doi.org/10.1501/Sporm_0000000253

Smith C. A. (1994). The warm-up procedure: To stretch or not to stretch. A brief review. *The Journal of Orthopaedic and Sports Physical Therapy*, *19*(1), 12–17. https://doi.org/10.2519/jospt.1994.19.1.12

Soriano, M. A., Jiménez-Reyes, P., Rhea, M. R., & Marín, P. J. (2015). The optimal load for maximal power production during lower-body resistance exercises: A meta-analysis. *Sports Medicine*, *45*(8), 1191–1205. https://doi.org/10.1007/s40279-015-0341-8

Thompson, S. W., Lake, J. P., Rogerson, D., Ruddock, A., & Barnes, A. (2023). Kinetics and kinematics of the free-weight back squat and loaded jump squat. *Journal of Strength and Conditioning Research*, *37*(1), 1–8. https://doi.org/10.1519/JSC.0000000000004186

Turner, T. S., Tobin, D. P., & Delahunt, E. (2015). Optimal loading range for the development of peak power output in the hexagonal barbell jump squat. *Journal of Strength and Conditioning Research*, *29*(6), 1627–1632. https://doi.org/10.1519/JSC.0000000000000802

VanHeest, J. L. (2003). Energy demands in the sport of volleyball. In J.C. Reeser & R. Bahr (Eds.), *Handbook of Sports Medicine and Science: Volleyball* (2nd ed.). Hoboken, NJ: Blackwell Science Ltd.

Wakefield, C. B., & Cottrell, G. T. (2015). Changes in hip flexor passive compliance do not account for improvement in vertical jump performance after hip flexor static stretching. *Journal of Strength and Conditioning Research*, *29*(6), 1601–1608. https://doi.org/10.1519/JSC.0000000000000794

Ziv, G., & Lidor, R. (2010). Vertical jump in female and male volleyball players: A review of observational and experimental studies. *Scandinavian Journal of Medicine & Science in Sports*, *20*(4), 556–567. https://doi.org/10.1111/j.1600-0838.2009.01083.x

CITING

Yarkın, G., Uysal, A.A., Bereket Yücel, S. & Özkol, M.Z. (2024). Effects of static stretching of antagonist muscles on lower extremity power output in elite female volleyball players. *International Journal of Sport Exercise and Training Sciences - IJSETS*, 10(4), 257-267. DOI: 10.18826/useeabd.1578359