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Antagonist Static Stretching Between Sets Improves Leg Press Repetition Performance in Adolescent Female Volleyball Players: A Randomized Crossover Within-Subject Design

Mehmet Tahir Özdemir [1], Zarife Pancar [2,*], Muhammet Taha İlhan [1], Muhammed Kaan Darendeli [1], Burak Karaca [1], Ali Muhittin Taşdoğan [3], Gian Mario Migliaccio [4,5,*] and Luca Russo [6]

1 Department of Physical Education and Sports, Institute of Health Sciences, Gaziantep University, Gaziantep 27350, Turkey; tahailhan91@gmail.com (M.T.İ.)
2 Department of Physical Education and Sport, Faculty Sport Science, Gaziantep University, Gaziantep 27310, Turkey
3 Faculty of Health Sciences, Hasan Kalyoncu University, Gaziantep 27100, Turkey
4 Department of Human Sciences and Promotion of the Quality of Life, San Raffaele Rome Open University, 00166 Rome, Italy
5 Maxima Performa, Athlete Physiology, Psychology and Nutrition Unit, 20126 Milan, Italy
6 Department of Theoretical and Applied Sciences, eCampus University, 22060 Novedrate, Italy
* Correspondence: z_pancar@hotmail.com (Z.P.); gianmario.migliaccio@uniroma5.it (G.M.M.)

Abstract

This study aimed to investigate the effect of antagonist static stretching applied between sets during resistance training on the number of repetitions of leg press exercise in young volleyball players. For this purpose, a total of 16 female active volleyball players (age 15.50 ± 0.52 years; height 167.25 ± 6.10; body mass 57.00 ± 5.98) participated voluntarily. The athletes participating in the study visited the laboratory five times. In the first session, anthropometric measurements were taken. In the second session, their 10 repetition maximums (RTs) were recorded, and in the third session, 10 control RTs were recorded. In the other two sessions, athletes were randomly assigned to two experimental protocol treatments in accordance with the crossover experimental design. In the traditional application, leg press exercise was performed as four sets with their own maximums and 2 min of passive rest between sets. In the experimental application, the participants performed four sets of leg press exercise with ten repetitions of their own maximums until concentric exhaustion, and static hamstring stretching was applied continuously for 30 s over 2 min between sets. All participants participated in both application protocols in different sessions. SPSS 20.0 package programed and GraphPad Prizm 8 graphics program were used for the analysis of all data. Data were analyzed at 0.05 significance level. In the findings obtained, Group* application interaction was found to be statistically significant according to the application and groups ($F = 4.198$, $p = 0.016$, $\eta_p^2 = 0.219$). In the leg press repetitions, statistical significance was found in favor of the experimental treatment in the third and fourth sets. This study shows that antagonist static stretching applied between sets positively affects resistance training performance by increasing the number of repetitions in leg press exercise in young female volleyball players.

Keywords: adolescent athletes; volleyball; antagonist stretching; resistance training; repetition performance

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Academic Editor: Mon-López Daniel

Received: 10 August 2025
Revised: 4 September 2025
Accepted: 9 September 2025
Published: 11 September 2025

Citation: Özdemir, M.T.; Pancar, Z.; İlhan, M.T.; Darendeli, M.K.; Karaca, B.; Taşdoğan, A.M.; Migliaccio, G.M.; Russo, L. Antagonist Static Stretching Between Sets Improves Leg Press Repetition Performance in Adolescent Female Volleyball Players: A Randomized Crossover Within-Subject Design. *Appl. Sci.* **2025**, *15*, 9933. https://doi.org/10.3390/app15189933

1. Introduction

Resistance training is a fundamental method for enhancing muscular strength, endurance, explosive power, and functional capacity, and is particularly important in sports such as volleyball, where frequent jumping, rapid directional changes, and high-intensity efforts place high demands on lower extremity strength [1,2]. Optimizing resistance training in volleyball is therefore crucial for both performance enhancement and injury prevention [3,4]. The strategy used for inter-set rest can directly influence subsequent performance, and while traditional approaches rely on passive rest, active rest methods have recently gained attention for their potential to accelerate recovery and enhance neuromuscular readiness [5–7].

The mechanism of reciprocal inhibition suggests that stretching antagonist muscles may temporarily increase the ability of agonist muscles to generate force. If this assumption is confirmed, inter-set stretching would represent a practical and effective form of active rest, potentially superior to traditional passive pauses [8–10]. Specifically, static stretching of the hamstring group may enhance the functional efficiency of the quadriceps, leading to increased repetition capacity and force production in compound lower limb exercises such as the leg press [11,12]. However, studies investigating the effects of this protocol in adolescent female athletes remain scarce.

Adolescent athletes possess a greater neuromuscular plasticity compared to adults, enabling them to generate faster and more robust adaptive responses to external stimuli [13]. Consequently, the application of antagonist static stretching protocols between sets in adolescent female volleyball players may induce significant differences in performance outcomes [14]. Therefore, the purpose of this study was to investigate the effect of an inter-set antagonist static stretching protocol on the number of repetitions performed during the leg press exercise in adolescent female volleyball players. Given the limited number of studies addressing this specific topic in the existing literature, the present study aims to fill a critical gap in the field of sports science and provide novel strategic insights for the optimization of resistance training programs. Therefore, the present study aims to provide initial evidence on the effectiveness of inter-set antagonist static stretching in adolescent female volleyball players, which may translate directly into training practice and motor preparation strategies in team sports [15]. Adolescent female volleyball players are particularly exposed to lower limb overload due to frequent jumping and the progressive increase in training loads. The development of jump strength and the prevention of overuse injuries are therefore of primary concern in this population. Coaches, on the other hand, are continuously searching for simple, inexpensive, and effective methods to optimize training. Antagonistic static stretching between sets may represent such a practical strategy, potentially improving performance while simultaneously contributing to injury prevention.

2. Materials and Methods

2.1. Participants

This study was conducted with 16 adolescent female volleyball players (age: 15.50 $\pm$ 0.52 years; height: 167.25 $\pm$ 6.10 cm; body mass: 57.00 $\pm$ 5.98 kg; BMI: 20.38 $\pm$ 2.60 kg/m^2) who had been engaging in structured volleyball training at least three times per week. All participants were randomly assigned to complete two distinct intervention protocols in a randomized crossover design. Inclusion criteria were as follows: (i) no history of major lower limb injuries within the past three months, (ii) absence of any chronic medical conditions, (iii) at least one year of consistent volleyball training experience, and (iv) familiarity with the leg press exercise.

Table 1 shows descriptive characteristics of the participants. Written informed consent was obtained from all participants and their legal guardians. The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Health and Sports Sciences at Gaziantep University (Meeting No: 03; Date: 15 February 2024; Decision No: 2024-4/439700).

Table 1. Descriptive characteristics of the participants.

Variable	N	Mean	Std. Dev.
Age (years)	16	15.50	0.52
Height (cm)	16	167.25	6.10
Body Mass (kg)	16	57.00	5.98
BMI (kg/m^2)	16	20.38	2.60
10 RM (kg)	16	111.56	15.35

Note: BMI = Body Mass Index; 10 RM= maximum load lifted for 10 repetitions on the leg press exercise.

2.2. Study Design

This study was structured using a randomized crossover design. Participants were randomly assigned to complete both the experimental and control protocols on separate days. All testing procedures were conducted during five separate sessions between 09:00 and 11:00 a.m. to minimize hormonal fluctuations. Variables such as biological rhythms and dietary habits were standardized across all participants. Participants were instructed to obtain at least eight hours of sleep the night before each test session, and sleep duration was confirmed via a brief questionnaire. To standardize pre-exercise nutrition, participants were required to refrain from strenuous physical activity for 24 h prior to testing and consume a carbohydrate rich meal containing approximately 300–500 kcal three hours before testing [16]. Each session began with a standardized warm-up consisting of five minutes of low intensity cycling followed by 10 bodyweight repetitions of the leg press exercise.

All static stretching exercises throughout the protocols were supervised by the same researcher to ensure standardization in application technique and duration. The experimental and control protocols were assigned using a randomized crossover design. Each participant completed one experimental protocol and one control protocol on separate days. Randomization was implemented to minimize potential order effects such as learning or accumulated fatigue. This ensured that any performance differences observed could be attributed solely to the protocol itself. Participants' nutritional intake was standardized prior to testing. They were instructed to sleep for at least eight hours the night before each session, and sleep duration was verified using a brief questionnaire. On non-testing days, participants followed diets matched for calorie content and macronutrient composition. Hydration guidelines were also provided, and participants were encouraged to maintain consistent fluid intake before and during testing.

Participants were informed not to engage in any unscheduled physical activities or deviate from their regular training routines throughout the study period. Individual training durations and intensities were recorded to monitor training load. These controls were applied to minimize the influence of external fatigue or overload on performance outcomes. For any session in which a participant reported inadequate sleep, the testing was rescheduled within the same week to maintain consistency.

2.3. Implementation of Experimental Protocols

Control Protocol: Participants performed the leg press exercise using their individually determined 10-repetition maximum (10RM) load. Each set was continued until volitional failure. A passive rest period of two minutes was provided between sets [17].

Experimental Protocol: The experimental protocol mirrored the control protocol in terms of load and exercise volume, consisting of four sets of leg press at 10RM (Figure 1). However, within each 2 min inter-set rest interval, a 30 s static stretching exercise targeting the hamstring muscle group (seated forward flexion) was integrated [12,14]. The stretching was performed immediately prior to each set, followed by 90 s of passive rest (Figure 2). The intensity of the stretch was maintained below the participant's pain threshold, and the procedure was supervised by the same researcher for all participants to ensure consistency in application [14,18,19].

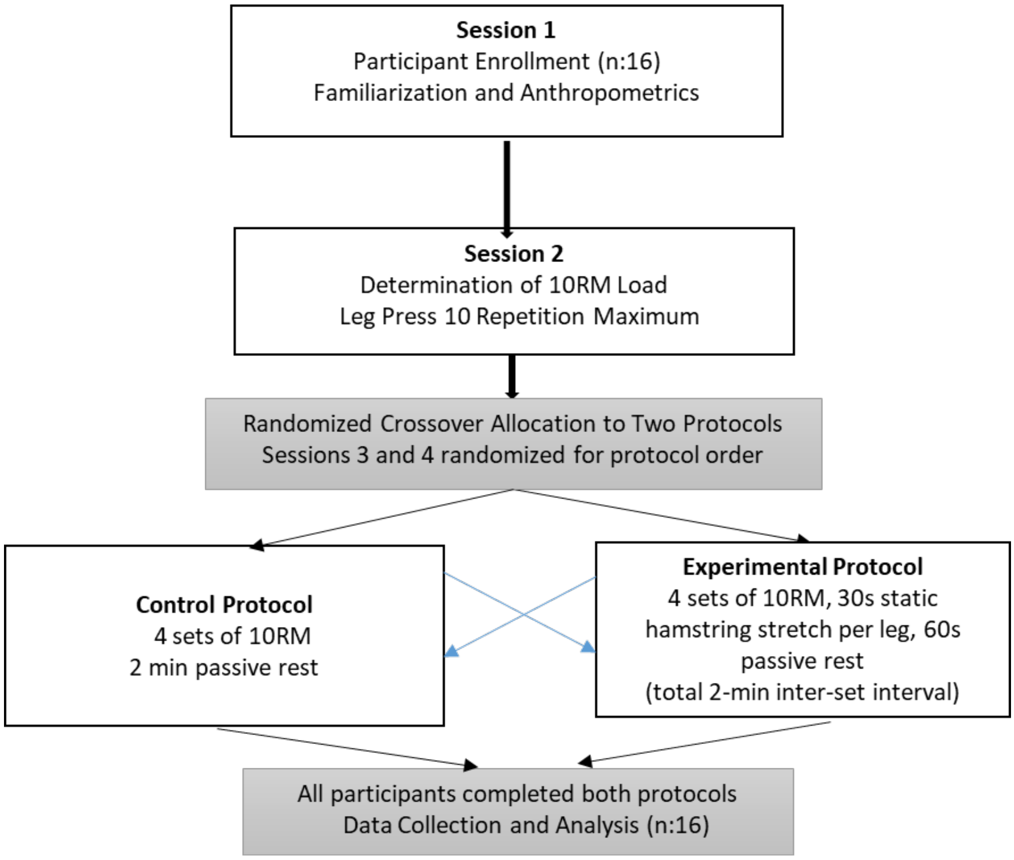

Figure 1. Overview of the experimental design and protocol allocation.

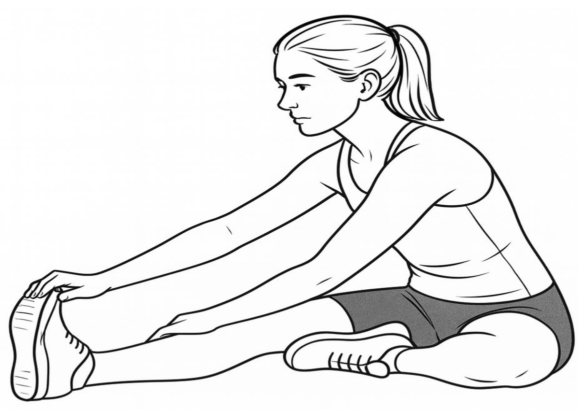

Figure 2. Illustration of the seated hamstring static stretch applied between sets in the experimental protocol.

This protocol was based on the neuromuscular principle of reciprocal inhibition, which suggests that stretching the antagonist muscle may reduce its neural drive, thereby facilitating more effective activation of the agonist muscle during subsequent exertion [20]. In this case, hamstring stretching was intended to reduce opposing resistance during quadriceps-dominant leg press movements, potentially improving performance outcomes such as repetition count and force production. Moreover, static stretching may transiently alter muscle stiffness and viscoelastic properties, enhancing joint range of motion and movement efficiency during resistance tasks [18,21].

2.4. Anthropometry

Participants were instructed to refrain from eating for at least 8 h prior to the anthropometric measurements, to avoid alcohol consumption in the 24 h preceding testing, and to abstain from strenuous physical activity. They were also instructed to minimize fluid intake and to empty their bladder before the assessment. Height was measured using a stadiometer (SECA, Hamburg, Germany) with an accuracy of 0.1 cm, and body weight was measured using an electronic scale (SECA, Hamburg, Germany) with an accuracy of 0.1 kg, following standardized anthropometric procedures [22]. Body mass index (kg/m^2) was calculated using the height and body weight values [23,24].

2.5. Ten Repetition Maximum (10RM) Test

To determine individual training loads, a 10-repetition maximum (10RM) test was conducted for the leg press exercise. The 10RM test has been widely used and validated as a reliable method to determine training loads in resistance exercise [25,26]. Testing was performed over two sessions spaced 48–72 h apart to ensure reliability. All tests were conducted between 09:00 and 11:00 a.m. under standardized conditions. Prior to testing, participants received detailed instruction and demonstrations of proper technique. The 10RM was defined as the maximum load with which a participant could complete exactly ten repetitions using correct form and full range of motion. During testing, the seat position and foot placement were standardized: knees at ~90° in the starting position, feet shoulder-width apart on the mid-lower platform, and hands on the grips. Rest intervals of 3–5 min were given between attempts. This protocol was used to ensure individualized loading and enhance the internal validity and standardization of exercise intensity across participants [25,26].

2.6. Statistical Analysis

Data are presented as mean ± standard deviation (SD). The Shapiro–Wilk test was used to assess the normality of the distribution. For variables not meeting normality assumptions, skewness and kurtosis values within ±2 were considered indicative of acceptable normal distribution. Mauchly's test of sphericity was applied to evaluate the assumption of sphericity. In cases where this assumption was violated, the Greenhouse–Geisser correction was applied. A two-way repeated measures ANOVA (2 × 4: protocol × set) with a 95% confidence interval was used to examine interaction effects. When significant main effects or interactions were detected, Bonferroni adjusted post hoc tests were conducted. Paired samples *t*-tests were used to compare differences between protocols within the same set. Effect sizes were calculated using partial eta squared (η_p^2), and thresholds were interpreted as follows: $\eta_p^2 = 0.01$ (small effect), $\eta_p^2 = 0.06$ (moderate effect), $\eta_p^2 = 0.14$ (large effect). All statistical analyses were performed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA), and graphical illustrations were created using GraphPad Prism 8 (GraphPad Software Inc., San Diego, CA, USA). The level of statistical significance was set at $p < 0.05$.

3. Results

The effects of the inter-set antagonist static stretching protocol on the number of repetitions performed in the leg press exercise were analyzed using a two-way repeated measures ANOVA (group × set). Descriptive statistics, including means and standard deviations, are presented in Table 2. The statistical results demonstrated significant main effects for set and protocol, as well as a significant interaction effect between group and protocol. These findings indicate that the number of repetitions varied significantly across sets and that the experimental condition had a greater impact on repetition performance than the control condition, particularly in later sets.

Table 2. Statistical analysis of group and protocol effects.

			Group			Protocol			Group × Protocol		
Group	**Set**	**Mean ± SD**	**F**	***p***	**η_p^2**	**F**	***p***	**η_p^2**	**F**	***p***	**η_p^2**
Control	Set 1	10.63 ± 0.96	17.313	0.001	0.536	10.817	0.000	0.419	4.198	0.016	0.219
	Set 2	11.69 ± 1.14									
	Set 3	11.13 ± 0.72									
	Set 4	11.00 ± 0.73									
Experimental	Set 1	10.75 ± 1.00									
	Set 2	12.19 ± 1.17									
	Set 3	12.50 ± 1.10									
	Set 4	12.56 ± 1.26									

SD = Standard Deviation; η_p^2 = Partial Eta Squared; Statistical significance was set at $p < 0.05$.

The analysis of the number of repetitions performed in the leg press exercise revealed a significant main effect for set (F = 17.313, p = 0.001, η_p^2 = 0.536), indicating that repetition performance significantly varied across the four sets. A significant main effect for protocol was also observed (F = 10.817, p = 0.000, η_p^2 = 0.419), suggesting that the type of protocol (experimental vs. control) had a notable impact on performance. Importantly, a significant group × protocol interaction was found (F = 4.198, p = 0.016, η_p^2 = 0.219), indicating that the difference in repetition performance across sets was influenced by the protocol applied. This interaction reflects that participants in the experimental condition (with inter-set antagonist static stretching) performed more repetitions, particularly in the later sets (Sets 3 and 4), compared to the control condition with passive rest. Descriptive results showed that while repetition numbers remained relatively stable across sets in the control group, a progressive increase was observed in the experimental group. Specifically, mean repetitions in the experimental group increased from 10.75 in Set 1 to 12.56 in Set 4, whereas the control group peaked in Set 2 and declined thereafter.

As shown in Table 3, significant differences between the control and experimental conditions emerged in Set 3 and Set 4 ($p < 0.05$), where the experimental group consistently performed more repetitions. Additionally, the total number of repetitions was significantly higher in the experimental protocol (12.00 ± 0.16) compared to the control (11.11 ± 0.12), indicating a cumulative benefit of inter-set antagonist static stretching.

Table 3. Comparison of mean repetitions between control and experimental protocols by set.

	Control (Mean ± SD)	**Experimental (Mean ± SD)**	**Difference**	**Significance**
Set 1	10.63 ± 0.96	10.75 ± 1.00	0.12	$p > 0.05$
Set 2	11.69 ± 1.14	12.19 ± 1.17	0.50	$p > 0.05$
Set 3	11.13 ± 0.72	12.50 ± 1.10 [a]	1.37	$p < 0.05$
Set 4	11.00 ± 0.73	12.56 ± 1.26 [a]	1.56	$p < 0.05$
Total	11.11 ± 0.12	12.00 ± 0.16 [b]	0.89	$p < 0.05$

[a] Significantly different from the control group for that specific set ($p < 0.05$). [b] Significantly different between groups in total repetitions ($p < 0.05$). $p > 0.05$ = not significant.

Significant differences were observed between the control and experimental protocols in Set 3 (t = −4.371, df = 15, p = 0.001) and Set 4 (t = −4.948, df = 15, p = 0.000). These findings indicate that participants in the experimental condition, which incorporated inter-set antagonist static stretching, performed significantly more repetitions in the later sets compared to the control condition with passive rest (Table 4). No significant differences were detected (Figure 3) in Sets 1 and 2 ($p > 0.05$).

Table 4. Paired Samples *t*-test results between control and experimental protocols by set.

Comparison	MD	SD	t	df	Sig. (2-Tailed)
Control Set 1–Experimental Set 1	−0.13	1.41	−0.355	15	0.728
Control Set 2–Experimental Set 2	−0.50	1.79	−1.118	15	0.281
Control Set 3–Experimental Set 3	−1.38	1.26	−4.371	15	0.001
Control Set 4–Experimental Set 4	−1.56	1.26	−4.948	15	0.000

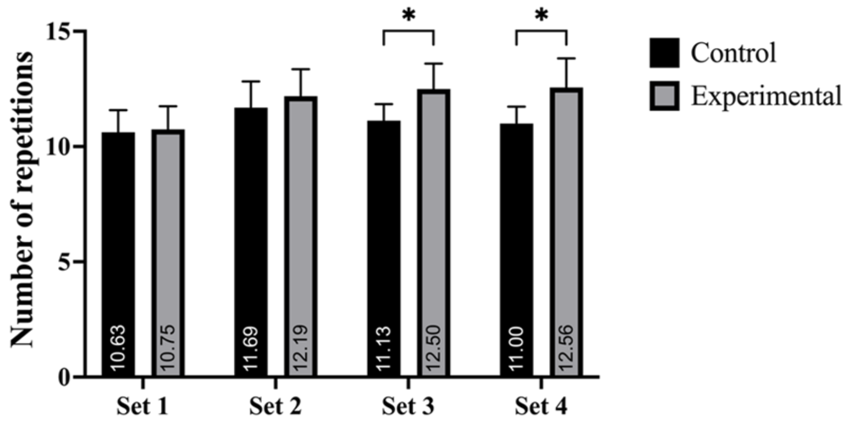

Figure 3. Comparison of repetition counts between control and experimental protocols across sets. Values are presented as mean ± standard deviation. Asterisks indicate statistically significant differences between groups ($p < 0.05$).

4. Discussion

This study aimed to examine the effects of inter-set antagonist static stretching (ASS) on the number of repetitions performed during the leg press exercise in adolescent volleyball players. The results demonstrated that applying ASS between sets significantly increased repetition performance compared to the control condition without stretching. These findings are consistent with previous research suggesting that antagonist stretching may enhance neuromuscular efficiency and improve force production.

The current findings, particularly the significant increase in repetitions observed in the third and fourth sets, partially align with earlier studies. However, some research has reported that antagonist static stretching may either reduce or have no effect on force out-put [12,18]. These discrepancies may be attributed to factors such as the duration of stretching (e.g., 30 s versus 90 s), the type of exercise performed (isotonic vs. isometric), participants' training background, or the specific muscle groups targeted [20]. Notably, prolonged static stretching (>60 s) has been shown to temporarily decrease passive stiffness of the muscle-tendon unit and reduce motor unit firing rates [27]. In the present study, the use of a short-duration (30 s) and well-controlled stretching protocol may have helped avoid these negative effects and facilitated positive neuromuscular adaptations.

The inclusion of female athletes in this study is noteworthy, as previous research has reported that women generally exhibit greater muscle elasticity than men, which may contribute to a more favorable response to stretching protocols [28–31]. Conversely, studies conducted on male athletes have shown that the effects of antagonist stretching on force production may be more limited compared to females, potentially due to higher muscle stiffness and lower elasticity in men [9,32]. Although static stretching is traditionally employed to improve flexibility, it has also been reported to enhance force production when applied to antagonist muscle groups during inter set rest intervals [14]. In the present study, static stretching of the hamstrings likely enhanced quadriceps function, resulting in increased repetition performance during the leg press exercise. This finding suggests that reducing tension in the antagonist muscle may facilitate more efficient activation of the primary mover [9,33].

The performance enhancing effects of inter set antagonist static stretching may not be solely attributed to reciprocal inhibition, but may also involve mechanisms such as autogenic inhibition, presynaptic inhibition, and spinal level reflex modulation [20]. Static stretching may reduce intramuscular tension by stimulating Golgi tendon organs, thereby improving agonist muscle function [10]. Additionally, temporary viscoelastic relaxation following stretching can reduce passive resistance from the antagonist, allowing the agonist to generate force with less opposition [27]. Collectively, these mechanisms may contribute to improved neuromuscular coordination and help counteract fatigue as sets progress. Traditionally, passive rest strategies have been favored during resistance training to prevent fatigue accumulation and promote recovery [17]. However, in this study, antagonist static stretching considered a form of active rest produced superior performance outcomes compared to passive rest. This may be attributed to enhanced blood flow and accelerated removal of intramuscular metabolites during active rest [28].

It is well established that neuromuscular adaptations are more dynamic in young athletes [13,34]. In the present study, participants aged 15–16 years appeared to adapt quickly to the implemented stretching protocol, which was reflected in improved performance outcomes. This finding suggests that inter set antagonist static stretching (ASS) may serve as a valuable strategy in optimizing resistance training for adolescent athletes. Studies involving adult athletes (ages 18–35) have also reported beneficial effects of ASS on strength and repetition performance [17,35]. However, recovery capacity and muscular endurance may differ in this age group compared to adolescents. For instance, Aguilar et al. [28] reported that in adult males, ASS produced favorable effects, particularly during high load resistance exercises. These results suggest that the improvements observed in adolescents may stem not only from heightened neuromuscular plasticity but also from reduced antagonist muscle interference. In older populations (>40 years), reduced musculoskeletal elasticity and slower recovery capacity may limit the effectiveness of ASS. Behm et al. [14] found that the impact of static stretching on strength performance was less pronounced in older individuals than in younger counterparts. This could be attributed to age related declines in soft tissue elasticity and neuromuscular control mechanisms. Overall, the findings of the current study indicate that ASS may have direct effects not only on flexibility and mobility but also on muscular strength and endurance. From a practical standpoint, incorporating short duration (30 s) ASS between sets during multi set resistance training could be an effective strategy to enhance training volume, particularly in programs targeting muscular endurance [36,37].

Based on the findings of this study, a structured inter set stretching approach resembling a functional rest strategy may be formalized as part of training programs. This protocol involves a brief static stretch applied to the antagonist muscle group, followed by minimal passive rest before commencing the next set. While similar approaches have been described in isolated studies, this application specifically in adolescent female volleyball players introduces a novel context and implementation scenario [38,39]. This application may be particularly advantageous in sports that emphasize lower limb performance, such as volleyball, basketball, and handball. Conducted specifically in adolescent female athletes, the present study expands the limited body of literature on this topic and opens new avenues for research across different age groups and genders. Similar protocols should be tested in other sports disciplines to determine whether the observed effects can be generalized. Nevertheless, some limitations should be acknowledged. The small sample size and the exclusive inclusion of female volleyball players may restrict the generalizability of the findings. Future studies should aim to test the efficacy of this protocol in larger and more diverse athlete populations across various sporting contexts [40–42].

Another potential limitation of the present study concerns the menstrual cycle of the participants. Although all experimental sessions were conducted in the morning hours under standardized conditions, and none of the participants reported menstrual-related symptoms (e.g., dysmenorrhea, fatigue, or irregularities) that could affect performance, it is acknowledged that hormonal fluctuations across the menstrual cycle may influence exercise outcomes. However, given the short duration of the crossover design, the potential impact of menstrual cycle phases was considered negligible. Another limitation is the lack of objective indicators of fatigue or neuromuscular activation, such as EMG or HRV, which could have provided deeper insights into the underlying mechanisms.

In conclusion, the findings of this study demonstrate that antagonist static stretching protocols can enhance resistance training performance in adolescent female volleyball players. The results suggest that this approach may not only improve flexibility and mobility but also boost repetition performance and force output. Testing this strategy in different populations may contribute to the development of innovative training applications within the field of sports science.

5. Conclusions

This study demonstrated that incorporating inter-set antagonist static stretching (ASS) can enhance repetition performance during the leg press exercise in adolescent female volleyball players, particularly in the later sets of a multi-set resistance protocol. These findings suggest that ASS may serve as a practical and time-efficient strategy to improve training outcomes in this specific population. However, the results should be interpreted with caution due to the relatively small sample size and the narrow demographic focus. Further research involving larger and more diverse groups, including male and older athletes, as well as studies incorporating objective measures of neuromuscular activation, is warranted to confirm and extend these preliminary findings. Nevertheless, the present study provides initial evidence that may inform training practice and motor preparation strategies in youth team sports.

Author Contributions: Conceptualization, Z.P. and M.T.Ö.; methodology, M.T.İ., M.T.Ö. and M.K.D.; formal analysis, B.K., M.T.Ö., M.T.İ. and M.K.D.; investigation, A.M.T., M.T.İ., M.K.D., M.T.Ö. and Z.P.; data duration, Z.P., M.T.Ö., M.K.D. and L.R.; writing—original draft preparation, Z.P., M.T.Ö., M.K.D., B.K. and M.T.İ.; writing—review and editing, G.M.M., M.K.D., M.T.Ö., M.T.İ., A.M.T., Z.P. and L.R.; supervision, Z.P., G.M.M. and L.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Health and Sports Sciences at Gaziantep University (Meeting No: 03; Date: 15 February 2024; Decision No: 4/439700).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors would like to thank all athletes for their time and dedication to this study.

Conflicts of Interest: The authors declare no conflicts of interest.

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