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The Impact of Isometric Exercises on Correcting Upper Body Muscle Imbalances in Young Elite Badminton Players

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Abstract

Overhead athletes are at a higher risk of injury when the internal rotation strength of their dominant shoulder exceeds that of the non-dominant shoulder by 9%, and the external rotation strength is 14% greater in the dominant shoulder compared to the non-dominant shoulder.Though 15% of bilateral strength difference is recognized in the literature as an imbalance. This study examined the effect of isometric exercise on muscle imbalance in young elite badminton players. The study was conducted using an experimental design with pre-test and post-test methodologies. We included approximately 80 Malaysian elite badminton players, comprising 42 male and 38 females, with an average age of 15 years and a maturity level of 2.05 peak height velocity. Participants were randomly assigned to two groups. The experimental group followed a 12-week internal and external rotation isometric exercise regimen. Three key measurements were taken during the study: pre-test data collected before any intervention, post-test1 data after 4 weeks of isometric exercises (12 sessions), and post-test2 data after 12 weeks of isometric exercises (36 sessions). A MicroFET®2 digital handheld dynamometer was used to assess muscle imbalance, focusing on the internal and external rotations of the dominant and non-dominant shoulders. The results showed a significant improvement in the muscle imbalance of the experimental group. Post-tests 1 and 2 revealed considerable improvements in the muscle imbalance ratios ($p<0.01 \eta = 0.791, 0.807$). Isometric exercises were found to significantly influence muscle imbalance ($p<0.01$; $\eta = 0.769$). This study established a positive and significant interaction between isometric exercise repetitions and muscle imbalance within the experimental group. Overall, the findings concluded that isometric exercises can significantly decrease muscle imbalance, with positive and significant effects observed even after just 4 weeks of the intervention in the treatment group.

Keywords: *muscle imbalance; non-dominant shoulder; isometric exercises; genders; maturation*

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Introduction

Despite advancements in sports science, critical gaps persist in understanding how gender-specific training techniques influence intervention program design, particularly in addressing muscle imbalances in overhead athletes (Tatlici et al., 2021). Previous studies have highlighted significant strength imbalances in internal and external shoulder rotation as key risk factors for shoulder injuries (Tülin et al., 2019: Kamalden & Gasibat, 2021). For instance, Stausholm et al. (2021) found that adult badminton players exhibit lower external rotation strength compared to adolescents, suggesting a decline in this strength with age among elite athletes. However, the impact of training techniques tailored to gender remains underexplored.

In one-sided sports such as badminton, squash, and water polo, muscle imbalances are a prevalent concern. Tülin et al. (2019) and Kamalden and Gasibat (2021) have emphasized the need to address these imbalances, yet the application of targeted training methods remains limited. Weakness in the internal and external rotators of the shoulder, particularly in the dominant arm, has been empirically linked to a higher risk of shoulder injuries (Hadzic et al., 2014). Hadzic et al. (2014) demonstrated that an imbalance of 14% greater external rotation strength and 9% greater internal rotation strength in the dominant shoulder compared to the non-dominant shoulder increases injury susceptibility in overhead athletes. Nevertheless, little attention has been given to interventions targeting these specific rotational movements, which are essential for rotator cuff stability.

Existing research, such as Sung et al. (2016) on golfers and Nekooei et al. (2021) on water polo players, has provided sport-specific insights but has largely overlooked generalizable approaches to correcting shoulder muscle imbalances in overhead sports. Furthermore, while isometric exercises are recognized for their safety and efficacy in building strength and reducing pain (Anastasio, 2020), their role in addressing muscle imbalance, biomechanical adaptations, and injury prevention remains poorly understood (Kaldau et al., 2021).

Isometric exercises are widely employed by coaches due to their safety and effectiveness in building muscle strength and reducing pain (Anastasio, 2020). These exercises allow athletes to target specific muscle groups without excessive joint movement, making them particularly suitable for addressing muscle imbalances in overhead athletes. However, their effects on muscle imbalance, biomechanical adaptations, and injury prevention remain poorly understood due to a lack of comprehensive studies (Kaldau et al., 2021). By focusing on isometric internal and external shoulder exercises, this study seeks to explore their potential as a targeted intervention for correcting muscle imbalances, particularly in the non-dominant shoulder, where imbalances are more prevalent.

The duration of a training program can significantly influence its effectiveness in achieving desired outcomes, yet there is limited research on the optimal length of time required to correct muscle imbalances in overhead athletes. This study compares the effects of isometric exercises performed over two different durations (4 weeks) and (12 weeks) to determine the most effective timeline for achieving measurable improvements in strength. Previous studies have shown that measurable improvements in strength and muscle balance can begin as early as (4 weeks) (Anastasio, 2020), while more substantial changes often require (8–12 weeks) of consistent training (Kaldau et al., 2021). By selecting these two durations, the study can compare the short-term and long-term effects of isometric exercises on muscle imbalances. This study aims to address existing gaps by focusing on young, elite badminton players, a group for whom shoulder muscle imbalances remain under-researched. It seeks to evaluate the effectiveness of isometric exercises targeting internal and external shoulder rotations in reducing muscle imbalances, which are critical for injury prevention and optimal performance. Additionally, the study examines the impact of training duration, comparing short-term (4 weeks) and long-term (12 weeks) interventions to determine their effectiveness in improving strength in the non-dominant shoulder. This dual focus aims to provide evidence-based insights for designing tailored training programs for overhead athletes.

Materials and Methods

Research Design

For the present study, which intends to comprehend the cause-and-effect relationships of isometric exercises on the non-dominant shoulder, the current research design is suitable. The dependent variable or variables are measured both before and after the intervention (i.e., the pre-test and post-test) in a pre-test–post-test design (Wang et al., 2020). This entry discusses how the pre-test–post-test design differs from traditional experimental designs, how it is used to evaluate human services and education, potential risks to internal validity, problems with external validity, and strategies for improving the design (Siregar, 2021). In this study, the effects of 36 sessions, three times a week, of internal and external rotation isometric exercises for the non-dominant shoulder (14th week as post-test 1 and 12th week as post-test 2) on the imbalance of shoulder strength in elite badminton players for the experimental group were assessed.

Participants

Based on G*Power calculations, the required sample size for this study was determined to be 28 participants (14 per group), assuming a medium effect size, a significance level (α) of 0.05, and statistical power of 0.80. This sample size was calculated to ensure the robustness of the multivariate analysis, which incorporates seven independent variables, following Cohen's guidelines for statistical power analysis.

Eighty (80) junior elite badminton players (38 females and 42 males) from Kuala Lumpur, Malaysia, participated in this study. The participants were selected based on the following inclusion criteria: (1) being competitive elite players, (2) training regularly and frequently, (3) passing the Physical Activity Readiness Questionnaire (2022 PAR-Q+), and (4) being free of injuries. These criteria were implemented to ensure participant suitability and to minimize dropout rates during the study. Including a larger dataset was aimed at enhancing the statistical power and accuracy of the analysis, reducing the likelihood of errors and increasing the reliability of the results.

Regarding anthropometric data, the participants had an average weight of 51.86±9.07 kg, an average height of 162.54±16.88 cm, and an average body mass index (BMI) of 19.18±2.33 kg/m². The average parental height was recorded as 170.83±5.52 cm (mid-parental height), while the average arm span was 152.37±12.66 cm. The participants' peak height velocity (PHV) was calculated as 2.05±2.10, indicating a mature developmental level. To calculate the PHV and maturity status, the equations proposed by Moore et al. (2015) were

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used, which rely on age and standing height for both sexes. For females, the maturity stage (in years) was calculated using the formula: Maturity stage (years) = −7.709133 + (0.0042232 × [age × height]), and for males, the formula was: Maturity stage (years) = −7.999994 + (0.0036124 × [age × height]). Based on these maturity stage calculations, the maturity status of the participants was classified using the method suggested by Kozieł and Malina (2018). This classification divides participants into three categories: those within −1 to +1 years of PHV were classified as average maturity, those under −1 year of PHV were classified as early maturing, and those over +1 year of PHV were classified as late maturing. This classification helps provide a clearer understanding of the players' developmental stages, which is crucial for interpreting the effects of training and exercise interventions on their physical and athletic performance (refer to Table 1).

Table 1. Descriptive Demographic Characteristics of the Respondent.

Variables		N	f	Mean	SD
Genders	Female	80	38		
	Male		42		
Dominant Hand	Left	80	8		
	Right		72		
Categories	Double	80	21		
	Mixed Double		14		
	Single		45		
Maturity Status	Average	80	30		
	Early		15		
	Late		35		
Age (in Years)	12 years old	80	10	14.74	1.78
	13 years old		9		
	14 years old		10		
	15 years old		12		
	16 years old		18		
	17 years old		21		
Experience (in Years)	5 years	80	19		
	6 years		24		
	7 years		17		
	8 years		14		
	9 years		4		
	10 years		2		
Weight (Kg)		80		51.86	9.07
Height (Cm)		80		162.54	16.88
BMI (Kg/m^2)		80		19.18	2.33
Father Height (Cm)		80		170.83	5.52
Arm Span (Cm)		80		152.37	12.66
Maturity Results		80		2.05	2.10

To make sure there was no bias in the sample selection for the experimental and control groups in this study, the researcher used a random sample approach (on the group selection). As stated by Chua (2011), random sampling, in which each participant has an equal chance of participating, is one kind of probability sampling procedure that is commonly used in evaluations. Participants in the current study were split into two groups: the experimental group and the control group. There were 40 players in total for the experimental group (22 males and 18 females). Temporarily, the control group consisted of 20 male elite badminton players and 20 female badminton players with different levels of maturity.

Furthermore, every participant reported that they work out six times a week. Based in Bukit Kiara, Kuala Lumpur, Malaysia, the Kuala Lumpur Badminton Association is a training facility designed especially for professional badminton players. The players and their parents signed a consent form indicating their consent to participate in the study, which was approved by the University Putra Malaysia Departmental Ethics Committee (REFERENCE NO: JKEUPM-2022-007).

Experiment Procedure

In addition, the researcher gave each participant a detailed explanation of the test protocol, the tools utilized in the investigation, and the benefits and advantages of the study. Beginning with the players' anthropometric data, the study's participants' health and safety were monitored by gathering their responses to a medical history form and the 2022 PAR-Q+ (Nekooei et al., 2019). Every participant signed a consent form, which the researcher collected. During this stage, the pre-test phase of the experiment was initiated by the researcher (Figure 1 shows all stages).

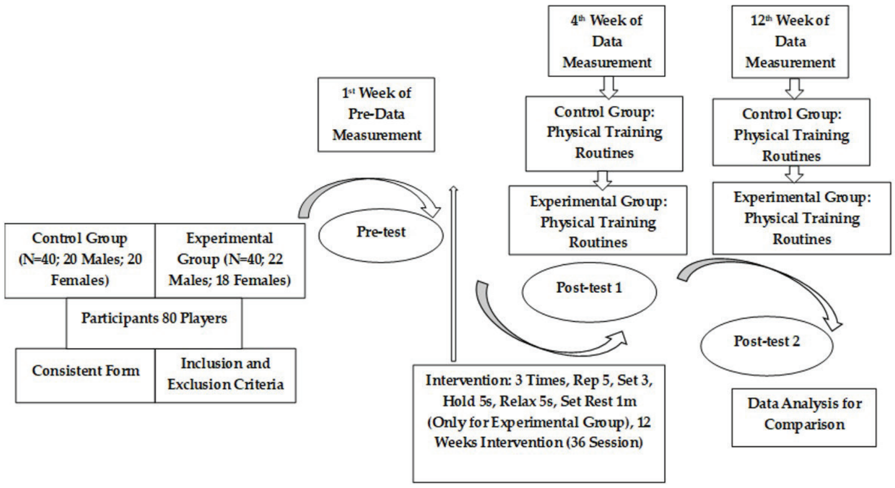

Figure 1. Experimental Procedures.

Both the experimental and control groups continued with individual physical training regimens after completing the pre-test evaluation, as described in Appendix A (https://mjssm.me/clanci/appendices/Gasibat-Appendix.pdf). To be more precise, the experimental group used isometric exercise as an intervention. The researcher made sure that the physical training routines were different from the intervention that the experimental group was doing. The researcher kept a careful eye on both groups and enforced rules throughout the procedure. Additionally, given that a warm-up was conducted before the start of the intervention, the researcher demonstrated to the experimental group the internal and external rotation isometric exercises for the non-dominant shoulder exclusively. These exercises were repeated for the next four weeks following the pre-test.

In this study, participants performed isometric exercises targeting the internal and external rotation of the non-dominant shoulder three times per week. The intervention was divided into two phases. Phase 1 lasted 4 weeks, during which participants completed 12 sessions, followed by the first post-test (Post-Test 1) to assess muscle imbalances between the dominant and non-dominant shoulders and the initial effects of the exercises. Phase 2 extended the intervention for an additional 8 weeks, resulting in a total of 36 sessions over 12 weeks. At the end of this period, the final post-test (Post-Test 2) was conducted to evaluate the long-term effects of the isometric exercises on muscle imbalance and strength in the non-dominant shoulder. Control group participants were also tested at the same time points to compare their results with those of the experimental group. This structured approach provided insights into both the short-term and long-term outcomes of the intervention, with Figure 1 illustrating the entire process.

To track initial development and adaptation, the 4-week evaluation acts as an early checkpoint. This allows for the identification of early increases in muscle strength and the necessary program adaptations (Kloubec, 2010). By giving early feedback, it supports participant motivation and compliance (Shakudo et al., 2011). It also records early physiological changes that are necessary for eventual hypertrophy and strength improvements, such as enhanced motor unit recruitment and coordination (Folland & Williams, 2007).

The 12-week evaluation, which provides a thorough analysis of long-term neural and muscle changes, is the main indicator of the intervention's efficacy (Kraemer et al., 2002). Significant gains in strength and muscle hypertrophy are measured; these improvements usually show up after 8–12 weeks of regular exercise (Ahtiainen et al., 2005). By assessing after 12 weeks, it is ensured that the gains made during the training program are maintained and accurately reflect the program's adaptation (Häkkinen et al., 2000).

Assessment intervals as little as two weeks are too short to detect significant physiological changes or progress. Likewise, it is possible that six weeks will not adequately record notable increases in strength and muscle hypertrophy (Kraemer et al., 2002). As a result, a detailed evaluation of the intervention's influence on strengthening the non-dominant shoulder and preventing muscle imbalance is provided. In summary, a dual-assessment method at 4 and 12 weeks ensures a comprehensive comprehension of both short-term improvement and long-term training consequences.

All participants in the current study were free to carry on with their usual exercise regimens or training activities, and the researcher was not permitted to modify the training program in any way that would impair its synergy. In addition, the researcher gave each participant a detailed explanation of the test protocol, the tools utilized in the investigation, and the benefits and advantages of the study. Over the course of the 12-week intervention program, each participant will have three (3) measurements taken into account. The researcher made certain that the physical training regimens' subject matter was distinct from the intervention that the experimental group undertook.

The researcher kept a careful eye on both groups and enforced rules throughout the procedure. Additionally, the researcher showed the experimental group (but not the control group) how to perform isometric exercises for internal and external rotation on the non-dominant shoulder. To preserve the internal validity of the results, the investigators gave the experimental group exclusive access to single-blinded information on the intervention. Even though everyone trained together, measurements and demonstrations during the ensuing weeks were carried out in a separate location. This strategy made sure the intervention program was only used with the experimental group.

Internal and External Rotation Strength Test

The Digital Handheld Dynamometer (HHD) was selected for its cost-effectiveness, portability, and accuracy, making it a practical tool for measuring muscle strength in training environments (Schrama et al., 2014). In this study, the HHD (MicroFET2, Hoggan Health Industries) was used to assess bilat-

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eral shoulder internal and external rotation strength, with test positions standardized and detailed in Figures 2 and 3. These positions align with validated protocols from prior research (Coinceicao et al., 2018).

The participants warmed up with a warm-up regimen that included two (2) maximal isometric contractions in each direction, followed by a 30-second rest period (Coinceicao et al., 2018). The researcher gave the participants 5 seconds to apply force to the device on the shoulder's internal and external rotations of the affected muscle group before telling them to relax. For every shoulder and rotation (2 × internal rotation and 2 × external rotation in Newton), the maximal isometric strength of both internal and external rotation was measured using two repetitions. There was a 10-second break between each repetition in all tests and a 60-second break between strength testing (Coinceicao et al., 2018). The participants were vocally motivated by the tester during the force generation phase. The maximum value recorded from the two repetitions of each test session was used for analysis (Coinceicao et al., 2018). Muscle balance was assessed using the External Rotation/Internal Rotation Ratios (ER/IR X 100%) (Stausholm et al., 2021). The researcher ran every test to gather pre-test data on the first testing day. The pre-test, which is planned to happen early in the intervention program week, comprised measurements of the internal and exterior rotation, as described below. At the training location, the exams were held in the evening. The study's post-test was identical to the pre-test, with the same warm-up protocols and testing techniques. Post-tests were given to the participants on the final day of week four for (post-test 1) and twelve for (post-test 2).

Intervention Programme (Experimental Group)

Isometric exercises for the non-dominant shoulder for 12 weeks Maximum Voluntary Contraction: 70–80% (MVC). (see Table 2)

Figure 2. Shoulder External Rotation Measurement

Figure 3. Shoulder Internal Rotation Measurement

Table 2. Isometric Shoulder External and Internal Rotation Exercises.

Exercise	How to perform
Isometric Shoulder External Rotation (Figure 4)	The shoulder on which you are exercising should be closest to the wall. Bend your elbow 90 degrees, make a fist, and press the back of your hand into the wall as if you were rotating your arm outwards. Repeat 5 times, hold 5 s, relax 5 s, 3 sets, rest 1 m between sets, 3 times a week.
Isometric Shoulder Internal Rotation (Figure 5)	Position your body so that you are facing a door frame or an outside corner of a wall. The shoulder on which you are exercising should be near the door opening or corner. Bend your elbow 90 degrees, make a fist, and gently press into the corner wall or door jamb as if you were trying to rotate your hand inward towards your belly button. Repeat 5 times, hold 5 s, relax 5 s, 3 sets, rest 1 m between sets, 3 times a week.

Figure 4. Isometric Shoulder External Rotation

Figure 5. Isometric Shoulder Internal Rotation

Data Analysis

Two-way repeated measures ANOVA was employed to evaluate the effects of two independent variables training duration (4 vs. 12 weeks) and group (intervention vs. control) on dependent variables such as shoulder rotation strength and muscle imbalance. This method allowed for the assessment of within-subject effects (changes over time) and between-group differences while accounting for interaction effects between the two factors (Aljandali, 2017; Tabachnick et al., 2013). The analysis provided a robust framework for examining the influence of isometric training duration on key outcomes while controlling for individual variability.

Results

Two-way repeated-measures ANOVA was used to analyze continuous outcome variables in the presence of one or more independent factors to achieve the stated goal. The mean value of isometric exercises for muscle imbalance for both the experimental and control groups throughout the course of the 12-week intervention is displayed in the descriptive statistic (see Table 3). For example, there was a 28% difference in the pre-test mean value of isometric exercises for muscle imbalance between the experimental group (96.39±0.86 and 68.33±10.46). Additionally, there was a 17% difference in the mean value of isometric exercises for muscle imbalance for post-test 1 (96.39±0.86 and 79.28±5.88), and a 3% rapid decline in the mean value of isometric exercises for muscle imbalance for post- test 2 (96.39±0.86 and 93.51±1.68). According to descriptive statistics, there was a progressive trend towards muscle imbalance during isometric exercises in the mean value of the exercises.

Table 3. Descriptive Analysis of Isometric Exercises on Muscle Imbalance between Experimental and Control Group.

Variables		Mean	SD	N
	Experimental Group	96.39	0.86	40
PREDER/IR	Control Group	96.37	0.95	40
	Total	96.39	0.88	80
	Experimental Group	68.33	10.46	40
PRENDER/IR	Control Group	58.71	10.63	40
	Total	65.68	11.32	80
	Experimental Group	96.39	0.86	40
POST1DER/IR	Control Group	95.45	1.77	40
	Total	96.13	1.25	80
	Experimental Group	79.28	5.88	40
POST1NDER/IR	Control Group	67.29	11.54	40
	Total	75.98	9.47	80
	Experimental Group	96.39	0.86	40
POST2DER/IR	Control Group	96.38	0.92	40
	Total	96.39	0.87	80
	Experimental Group	93.51	1.68	40
POST2NDER/IR	Control Group	67.47	11.81	40
	Total	86.34	13.26	80

PREDER\IR= Pre-Test Dominant Ratio; POST1DER/IR= Post-Test 1 Dominant Ratio; POST2DER/IR= Post-Test 2 Dominant Ratio; PRENDER\IR= Pre-Test Non-Dominant Ratio; POST1NDER/IR= Post-Test 1 Non-Dominant Ratio; POST2NDER/IR= Post-Test 2 Non-Dominant Ratio

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The control group's pre-test mean value of muscle imbalance was found to differ by 37.7% between 96.37±0.95 and 58.71±10.63. Additionally, the average muscle imbalance values for post-test 1 and post-test 2 were 95.45±1.77 and 67.29±11.54, respectively, differing by 28.2% and 28.9%, respectively. According to descriptive statistics, there was no progression between post-test 1 and post-test 2, but there was a slight progressive trend towards muscle imbalance in the mean value of the muscle imbalance between the pre-test and post-test 1. For the control group, the mean value of muscle imbalance varied between 28.2% and 37.7% overall.

In this investigation, the association between isometric exercise and muscle imbalance during post-tests 1 and 2 was investigated using a two-way repeated-measures ANOVA. Muscle imbalance factors had the biggest influence on the model (Ƞ= 0.903), as shown in Table 4, and were significantly influenced with time (p=0.000). Additionally, the model parameters (refer to Table 4) show that post-tests 1 and 2 positively affect muscle imbalance (p=0.000; Ƞ=0.791). In conclusion, players' muscle imbalance ratios reduced over time (p=0.000; Ƞ= 0.807). As a result, the experimental group's muscle imbalance ratios also improved.

Table 4. Analysis of Two-Way ANOVA Repeated Measurement Effect of 4^{th} and 12^{th} Weeks on Isometric Exercises towards Muscle Imbalance.

Effect	Testing	Value	F	p	Partial Eta Squared
Muscle Imbalance	Wilks' Lambda	0.097[a]	998.381[b]	0.000	0.903
Post-test 1 vs Post-test 2		0.209[a]	200.914[b]	0.000	0.791
Muscle Imbalance * Post-test 1 vs Post-test 2		0.193[a]	221.544[b]	0.000	0.807

a. Design: Intercept + GROUP; Within Subjects Design: Muscle Imbalance + Post-Test 1 vs Post-Test 2 + Muscle Imbalance * Post-Test 1 vs Post-Test 2; b. Exact Statistic

The relationship between isometric exercise and muscle imbalance during post-test 1 and post-test 2 was investigated in this study using a two-way repeated measures ANOVA. As demonstrated by the within-subject effects tests following the sphericity assumption (refer to Table 5), the isometric exercise variables had a significant impact on muscle imbalance (p= 0.000; Ƞ= 0.762) and repetitions (or measurements) (p= 0.000; Ƞ= 0.903). Table 5 shows that there is a significant effect of isometric exercises on muscle imbalance (p= 0.000; Ƞ= 0.769).

Table 5. Test of Within-Subject Effects Test.

Effects		Mean Square	F	p	Partial Eta Squared
Muscle Imbalance	Sphericity Assumed	73888.301	998.381	0.000	0.903
Post-test 1 vs Post-test 2		3141.411	342.837	0.000	0.762
Muscle Imbalance * Post-test 1 vs Post-test 2		3172.993	355.975	0.000	0.769

The experimental group and the control group in Table 6 and Figure 6 demonstrate between subjects' effects; nonetheless, it is seen that both groups exhibit a substantial effect on the intervention with 43.4% (p=0.000; Ƞ =0.434). For a short time, the effects of isometric exercises (post-test 1 and post-test 2) on muscle imbalance were demonstrated by the tests on the between-subject effects and the pairwise comparison test (p=0.000). As a result, in the experimental group as opposed to the control group, there is a positive and significant interaction between the number of repetitions of isometric exercises and muscle imbalance (p=0.000).

Table 6. Test of Between-Subjects Effects (Experimental group vs Control Group).

Source	Mean Square	F	p	Partial Eta Squared
Intercept	3711093.754	35579.98	0.000	0.997
Group	8570.695	82.171	0.000	0.434
Error	104.303			

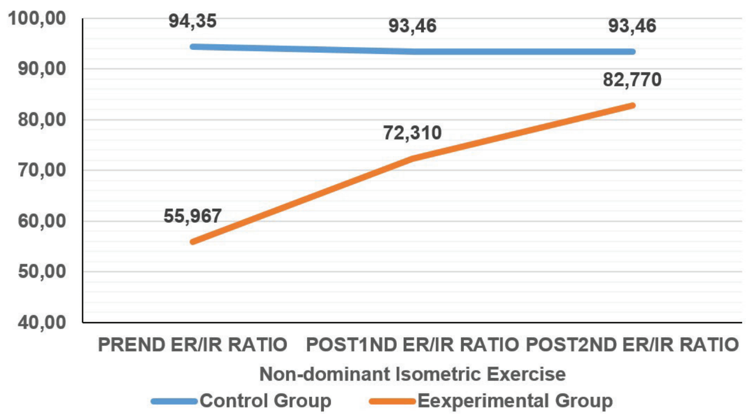

Figure 6. Marginal Mean Different for Non-dominant Shoulder.

Table 7. Multiple Pairwise Comparisons of Muscle Imbalance and Post-test 1 vs Post-test 2.

Muscle Imbalance	Muscle Imbalance	Mean Difference	p
Experimental group	Control Group	23.799*	0.000
Pre-Test vs Post-Test 1		-4.650*	0.000
Post-Test 1 vs Post-Test 2		-3.836*	0.000
Pre-Test vs Post-Test 2		-8.486*	0.000

Another way to put it is that as soon as the isometric exercises begin, and even up to four weeks later, they have a good and significant effect on the treatment group. Specifics of the results are shown in Table 7.

Discussion

This study shows that isometric exercises effectively reduce shoulder muscle imbalances in young elite badminton players, especially when performed over longer intervention durations. Athletes' ability to maintain muscle strength and balance is significantly impacted by isometric exercises and their length, as shown by statistical analysis. But timing and duration of exercise are also very important in helping athletes avoid abrupt, unforeseen injuries. This is mostly due to the development of muscle flexibility, which restores the chronically restricted equilibrium that can be brought about by things like fatigue, injuries, bad posture, or exercise habits (Du & Fan, 2023; Cools et al., 2014).

A two-way ANOVA with repeated measures was used to examine the connection between isometric exercises and muscle imbalance during the pre-test, post-test 1, and post-test 2 in this study. Time was found to have a considerable impact on the variables related to muscle imbalance in the study, with the model showing the most impact. Additionally, post-tests 1 and 2 had a positive impact on muscle imbalance. In conclusion, athletes' muscle imbalance lessened with time. As a result, participating in the experimental group enhances muscle balance. These results support the idea that specific isometric training can help elite badminton players' non-dominant shoulder muscles become more balanced. This is a significant discovery because it implies that professional badminton players may benefit from these exercises in terms of injury prevention and performance enhancement.

Although our results show that isometric exercises are beneficial, earlier studies such as Malliou et al. (2004) found that movements have shown to be beneficial for treating muscle imbalance in the rotator cuff muscle group, include pull-ups, lat pull-downs, push-ups, overhead presses, and reverse pull-ups. On the other hand, the intervention strategy differs noticeably. Unlike previous research that predominantly advocated intervention targeting the non-dominant side, the Malliou study included exercises for both the dominant and non-dominant shoulders (Kamalden & Gasibat, 2021; Tülin et al., 2019).

While Sung et al. (2016) focused primarily on exercises directly related to golf-specific motions, their findings on the benefits of core and non-dominant arm strength training offer parallels to our study's emphasis on the importance of targeted interventions for muscle balance. However, their work neglected to address fundamental movements, such as shoulder internal and external rotation, which are essential for overhead sports like badminton and golf. As demonstrated by Pennock et al. (2018), Hams et al. (2019), and Hadzic et al. (2014), deficits in shoulder internal and external rotation strength significantly increase the risk of injury and compromise rotator cuff support.

Hadzic et al. (2014) found that a 14% imbalance in external rotation strength between shoulders and a 9% difference in internal rotation strength in dominant versus non-dominant shoulders were strongly associated with higher injury risks in overhead athletes. These findings are consistent with our study, which demonstrates that isometric exercises significantly reduce shoulder muscle imbalances in young elite badminton players. Our study aligns particularly well with Rio et al. (2015), who highlighted the importance of isometric exercises in treating tendinopathy, noting their ability to reduce pain and enhance functionality. Moreover, Kinsella et al. (2017) underscored that isometric exercises outperform isotonic exercises (eccentric and concentric) in improving muscle performance, a finding that reinforces our approach to addressing muscle imbalances.

Additionally, our study supports Tiwari et al. (2011), who emphasized the importance of prolonged training duration for improving agility, balance, and muscle dexterity in badminton players. We observed that longer intervention durations with isometric exercises produced more pronounced reductions in shoulder muscle imbalances, highlighting the critical role of consistent, sustained training programs in preventing injuries and enhancing performance.

These consistencies underscore the efficacy of isometric exercises, particularly when applied with longer intervention durations, in addressing muscle imbalances and supporting young elite athletes in overhead sports.Sung et al. (2016), who emphasized isotonic training, provided useful insights into strength improvement; however, our findings distinctly highlight the specific benefits of isometric exercises in enhancing rotator cuff strength and addressing asymmetries. This distinction is further supported by Brumitt and Dale (2009), who observed that professional badminton players benefited from isometric exercises by increasing tendon stiffness and reducing injury risk. These observations align with our emphasis on consistency and structured, long-term training, which proved effective in significantly reducing shoulder muscle imbalances in young elite badminton players.

Parle et al. (2017) illustrated the potential of progressively lengthening isometric training sessions for managing and preventing injuries, particularly in patients with rotator cuff tendinopathy. This finding parallels our results, which demonstrate that extended durations of isometric training interventions contribute to greater reductions in shoulder imbalances and injury prevention. Similarly, Gerstner et al. (2022) and Sumartiningsih (2021) emphasized the long-term benefits of isometric training, showing improvements in muscle endurance and metabolic capacity. These studies resonate with our findings, reinforcing the importance of sustained isometric exercise programs in promoting functional strength and balance.

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Lum and Barbosa (2019) highlighted the relevance of isometric movements for persistent muscle activation, particularly in physical therapy and endurance sports. This underscores the broader applicability of our findings, as isometric exercises not only address muscle imbalances but also enhance rehabilitation efforts and reduce injury risks, making them an essential component of training regimens for athletes, especially those in overhead sports like badminton.

The practice of executing one to three sets of 5 to 10 repetitions of isometric contractions that last at least 5 seconds, as explained by Izraelski (2012) reaffirms the significance of prolonged timing and consistency in triggering muscle activity and building strength. The present study, in conjunction with other research findings, indicates that a clear consensus cannot be reached regarding the ideal duration for maintaining isometric exercises aimed at strengthening muscle imbalance. Nonetheless, it has been observed that greater consistency in these exercises is associated with increased physical agility or flexibility in individuals (Blomstrand et al., 2017). A review by Malliaras et al. (2015) on isometric exercises also recommended longer, more repetitive routine sessions in order to improve muscle tenacity and balance compared to participants who performed the same exercises for shorter amounts of time.

The individual context and goals of the training or rehabilitation program determine how long isometric exercises should last (Lim & Wong, 2018). Sports warm-up programs frequently include short isometric exercises to improve muscle strength and power, while longer-duration exercises are better for injury recovery and tasks requiring extended muscle engagement (Clifford et al., 2020). Our study examined the effects of 4-week and 12-week isometric exercises on shoulder muscle imbalance in young, professional badminton players. These ranges of time enable a thorough investigation of the ways in which exercise length affects the mitigation of muscle imbalance and improvement of shoulder stability (Clifford et al., 2020). This methodology is consistent with the concept that the length of exercise needs to be tailored to the unique requirements of the target group and the intended results (Birrer & Morgan, 2010).

The importance of length on the intervention outcomes was also taken into consideration in the results of the descriptive analysis (Table 4). This showed how to overcome muscle barriers and improve strength and ability through position-specific training techniques, which improves performance and endurance in the field. These outcomes supported the conclusions made by Bolotin and Bakayev (2016), who suggested that elite athletes perform isometric exercises with a focus on injury prevention.

As a result, our research adds to the increasing amount of data demonstrating the value of isometric exercises, particularly when it comes to treating muscle imbalance in the non-dominant shoulder. The present study's methodology is consistent with earlier research conducted by Malliou et al. (2004) and Kinsella et al. (2017); however, the disparity in intervention approaches and the necessity of taking into account fundamental movements in overhead sports, as suggested by some scholars such as Sung et al. (2016) and Hadzic et al. (2014), highlighted the significance of a customized and all-encompassing exercise regimen to optimize athletic performance and minimize the risk of injury. Our study's results are consistent with those of several other studies, such as Tiwari et al. (2011) and Parle et al. (2017). They demonstrated the value of extended duration, regularity, and isometric exercise in enhancing muscle strength, agility, balance, and preventing injuries in athletes and people undergoing rehabilitation.

These results underscore the need for coaches and trainers to incorporate structured, long-term isometric training into strength and conditioning programs for young athletes. Such programs can enhance shoulder stability, reduce muscle imbalances, and mitigate injury risks. For optimal outcomes, training plans should prioritize progressive overload and consistency, tailoring exercise duration to the specific performance or rehabilitation goals of the athlete.

Limitations and strengths

Research constraints refer to deficiencies or inadequacies in the study that might not always support the results of richer data. In this situation, future research must address a few shortcomings of the study, despite the significant benefits it has produced. First, only junior elite badminton players classified by Swann et al. (2015). as competitive-elite athletes were included in this study. The study's conclusions might therefore be applied to badminton players at different skill levels.

Second, due to psychophysiological factors related to human performance that are outside the researcher's control, there may be situations during the intensive intervention method where the participants provide performances inconsistently. Nonetheless, players are strongly urged to give them all during the data collection procedure. Because human interaction is always subject to changes based on preferences and the chance that they will give the study their all, these limitations are evident. The conditions and circumstances that may affect or limit the research data methodologies and analysis are indicated in the restrictions. The constraints in this study were unpredictable.

As previous academic studies have shown, physical activity or fitness levels in the non-dominant body side have not been measured or included very often because of the belief that their effects on interventions are restricted. Sung et al. (2016) conducted research that demonstrated this disregard, as they rarely evaluated or tested these variables. Prior studies have mostly examined the effectiveness of isometric exercise therapies for body part movement, gender, maturation stage, and other related characteristics. As a result, following the example given by Sung et al. (2016), the current study does not identify physical activity as a variable of interest.

Thus, in order to help elite badminton players, enhance and develop their performance and efficiency in the sphere of sports, the current study has been able to shed light on the relationship between isometric exercises, shoulder strength, and muscle imbalance. This study highlights the importance of isometric exercises in preventing elite athletes from experiencing previously unheard-of injuries during training, enhancing their performance, and above all improving their natural ability to move while also building their physical strength and endurance.

For athletes, muscle balance and agility are critical, and hundreds of sports agencies use this study as a guide. With the use of this study information, organizations will be able to reassess and introspect their current training regimen and adjust their tactics as necessary to ensure that athletes receive the greatest possible training and performance. Consequently, it is important to note that a thorough knowledge and comprehension of the isometric exercises' relationship to shoulder muscle strength would benefit millions of athletes worldwide by enabling them to assess the type of exercises they are performing and create the most effective training plan for improving muscle balance and flexibility. Even though the study's goal has been achieved, more thorough research procedures are needed to incorporate various badminton involvement levels. This would make the results more broadly applicable, which might result in more harmoniously important contributions to the discipline.

Conclusions

Isometric exercises significantly reduce muscle imbalance, with the experimental group showing statistically significant improvements in muscle balance between dominant and non-dominant shoulders across pre-test, post-test 1, and post-test 2. Trainers should prioritize longer intervention durations, such as twelve-week sessions, to promote sustained endurance and metabolic adaptations, while shorter durations, such as four weeks, may focus on immediate strength and power gains. Recommendations should align exercise duration with specific training or rehabilitation goals for optimal outcomes.

Informed Consent Statement

Written consent was obtained from parents of all subjects involved in the study.

Data Availability Statement

Data are available upon reasonable request.

Appendix A

Physical training routines for badminton (https://mjssm.me/clanci/appendices/Gasibat-Appendix.pdf

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