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The Effect of Arm Muscle Strength, Forward Torsion Flexibility And Wrist Flexibility On Smash Ability

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ABSTRACT

This study aims to examine the effect of arm muscle strength, forward trunk flexibility, and wrist flexibility on smashing ability in badminton extracurricular students at the UPT SPF SDI Unggulan BTN Pemda. This study also analyses the relationship between independent variables to understand the interaction patterns that occur in the context of smashing badminton ability. This study used a quantitative approach with a cross-sectional design and path analysis techniques. The study sample consisted of 20 badminton extracurricular students selected using a purposive sampling technique. The research instruments included a Push and Pull (expanding) Dynamometer to measure arm muscle strength, a Sit and Reach test for forward trunk flexibility, a goniometer for wrist flexibility, and a smash accuracy and speed test to measure smashing ability. Data were analysed using descriptive analysis and path analysis with SPSS version 25 software. Prerequisite tests included the Shapiro-Wilk normality test, linearity test, and multicollinearity test with a significance level of $\alpha = 0.05$. The results of the study showed that the average arm muscle strength was 11.95 (SD=2.39), forward trunk flexibility was 14.35 (SD=2.98), wrist flexibility was 10.60 (SD=1.76), and smash ability was 6.70 (SD=1.30). All variables were normally distributed ($p>0.05$) and had a linear relationship. The results of the regression test showed: (1) arm muscle strength had a significant effect on smash ability (R^2=0.962; t=6.134; p=0.000); (2) forward trunk flexibility had a significant effect on smash ability (R^2=0.962; t=2.127; p=0.004); (3) wrist flexibility had a significant effect on smash ability (R^2=0.962; t=0.633; p=0.003); (4) arm muscle strength significantly influences wrist flexibility (R^2=0.965; t=3.049; p=0.007); and (5) forward trunk flexibility significantly influences wrist flexibility (R^2=0.965; t=3.455; p=0.003). There is a significant direct influence of arm muscle strength (96.2%), forward trunk flexibility (96.2%), and wrist flexibility (96.2%) on the smash ability of extracurricular badminton students. In addition, a direct influence of arm muscle strength (96.5%) and forward trunk flexibility (96.5%) on wrist flexibility was found. The results of this study emphasise the importance of developing an integrated physical training program to improve smash ability, with a focus on strengthening arm muscles, increasing trunk flexibility, and optimising wrist mobility as physical components that interact with each other in supporting optimal smash technique performance.

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A. Conception and design of the study;
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INTRODUCTION

Badminton is a sport that demands an optimal combination of speed, precision, and high physical endurance from each player. Success in this sport is determined not only by technical skills such as smashes, drop shots, and lobs, but also depends heavily on physical condition that supports mastery of these techniques. In the context of modern badminton, the smash is one of the most effective attacking techniques, often determining victory in a match (Febrisyah et al., 2022; Sudiadharma & Ishak, 2018; Zuhri, 2019).

A smash is defined as an attack shot delivered at high speed, directed downwards with force and sharpness toward the opponent's court (Muh. Syahrul Saleh et al., 2024). The characteristics of this shot, delivered quickly and suddenly, produce a powerful and diving shot that can stifle an opponent's defence and win an immediate point. Therefore, mastering good smash technique is a fundamental requirement for every badminton player (Antoni, 2015; Artha, 2021).

Successfully executing an effective smash is inextricably linked to three main, interacting physical components. First, arm muscle strength plays a key role in producing a powerful and accurate shot. Adequate arm muscle strength allows players to hit the shuttlecock at high speeds and at sharp angles that are difficult for opponents to anticipate (Ahmad Saleh et al., 2022). Without optimal arm muscle strength, players will struggle to produce shots powerful enough to put pressure on their opponents. Second, forward trunk flexibility plays a crucial role in optimising the smash motion. The trunk, which encompasses the back, waist, and abdominal muscles, plays a role in the rotational and flexing movements of the body during the racket swing (Syah et al., 2024). Good trunk flexibility allows players to perform broader and more dynamic body movements, thus optimising the racket swing to produce maximum speed and angle. Lack of trunk flexibility can limit the body's range of motion, thereby reducing the efficiency of the smash (Tahir et al., 2018; Sahabuddin et al., 2022).

Third, wrist flexibility is a significant factor in controlling the shuttlecock with high precision. A flexible wrist provides an advantage in varying the angle and power of the shot, which can ultimately confuse the opponent and create opportunities for scoring points. Good wrist flexibility enables players to produce smashes with optimal accuracy and speed (Hasanuddin, M, 2019).

Although the theoretical relationship between these three physical components and smashing ability is understood, in practice, a gap remains between physical potential and actual performance. This is evident in the Badminton Extracurricular Students of the UPT SPF SDI Unggulan BTN Pemda, which has a large number of participants and adequate sports facilities, particularly national-standard badminton courts. However, their achievements in badminton have not yet shown satisfactory results compared to several other schools in South Sulawesi.

This situation is evident in several regional and national inter-school championships held in Makassar and the Sulawesi region, where athletes and students in the Badminton Extracurricular Activities (UPT SPF SDI Unggulan BTN Pemda) often fail to achieve optimal performance. This is despite efforts to ensure optimal performance, including the availability of qualified coaches, the provision of high-quality facilities and equipment, the establishment of a strong organisation, and support from educational institutions and the government.

This gap between potential and actual performance demonstrates the need for an in-depth study of the factors influencing students' smashing ability. A comprehensive understanding of the influence of arm muscle strength, forward trunk flexibility, and wrist flexibility on smashing ability is expected to provide a scientific basis for developing more effective and targeted training programs.

Based on this background, this study aims to empirically examine the influence of arm muscle strength, forward trunk flexibility, and wrist flexibility on smashing ability in students in the Badminton Extracurricular Activities (UPT SPF SDI Unggulan BTN Pemda). The results of this study are expected to contribute to the development of more optimal training methods to improve students' smashing abilities, thereby supporting the achievement of better performance in badminton competitions.

This study will answer the following research questions: 1) Is there a direct influence of arm muscle strength on smashing ability in the badminton extracurricular activity of the UPT SPF SDI Unggulan BTN Pemda? 2) Is there an influence of forward torso flexibility on smashing ability in the badminton extracurricular activity of the UPT SPF SDI Unggulan BTN Pemda? 3) Is there an influence of wrist flexibility on smashing ability in the badminton extracurricular activity of the UPT SPF SDI Unggulan BTN Pemda? 4) Is there an influence of arm muscle strength directly on wrist flexibility in the badminton extracurricular activity of the UPT SPF SDI Unggulan BTN Pemda? 4) Is there an influence of forward torso flexibility directly on wrist flexibility?

METHODS

This study used a quantitative method with a correlational approach. The aim was to examine the relationship and influence between the independent variables (arm muscle strength, forward trunk flexibility, and wrist flexibility) on the dependent variable (smashing ability). This study also analysed the relationships between the independent variables to understand the interaction patterns that occur within the context of smashing ability in badminton.

The research design used was a cross-sectional design with a path analysis approach to analyse the direct and indirect effects between variables. This design was chosen because it allowed researchers to measure all variables at a single point in time and analyse causal relationships between them simultaneously.

The path analysis model in this study can be described as follows:

Exogenous variables: Arm muscle strength (X_1) and forward trunk flexibility (X_2); Endogenous variables: Wrist flexibility (X_3) and smashing ability (Y).

The population in this study was all students participating in the badminton extracurricular activity at the UPT SPF SDI Unggulan BTN Pemda. The research sample consisted of 20 extracurricular badminton students selected using a purposive sampling technique. Data

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collection was conducted through tests and direct measurements of students' physical and technical abilities. The data collection process was carried out in three stages: 1) Explanation of the research objectives, informed consent, and warm-up. 2) Administering tests for each variable in a predetermined order. 3) Cool-down and evaluation of test results.

The research instruments included: 1) Arm Muscle Strength (X_1). Instrument: Push and Pull (expanding) Dynamometer. Validity: This test has been validated to measure arm muscle strength in badminton athletes. 2) Forward Trunk Flexibility (X_2). Instrument: Sit and Reach Test. Unit: Centimetres (cm). Procedure: Subjects sat with their legs straight, then bent forward as far as possible without bending their knees. Validity: This is a standard test for measuring trunk flexibility that has been tested for validity and reliability. 3) Wrist Flexibility (X_3). Instrument: Wrist Flexion and Extension Test using a goniometer. Unit: Degrees (°). Procedure: Measurement of the maximum angle of wrist flexion and extension in the anatomical position. Validity: A standard instrument for measuring wrist range of motion. 4) Smash Ability (Y). Instrument: Smash Accuracy and Speed Test. Unit: A combined score of accuracy and speed. Procedure: Subjects performed 12 smashes from a predetermined position. Assessment was based on target accuracy (40%) and smash speed (60%).

Data Analysis Techniques (Descriptive Analysis): Calculation of the mean, median, mode, standard deviation, maximum, and minimum values. Inferential Analysis: Prerequisite Tests (Normality Test: Using the Shapiro-Wilk test ($n<30$) to test for normal distribution of data). Linearity Test: Using the linearity test to test for linear relationships between variables. Multicollinearity Test: Using the VIF (Variance Inflation Factor) value to detect multicollinearity. Path analysis was used to answer the research problem formulation with the following structure:

Substructure 1: $X_3 = \rho_{31}X_1 + \rho_{32}X_2 + \varepsilon_1$ Substructure 2: $Y = \rho y_1X_1 + \rho y_2X_2 + \rho y_3X_3 + \varepsilon_2$

Where:

ρ_{31} = path coefficient of X_1 with respect to X_3

ρ_{32} = path coefficient of X_2 with respect to X_3

ρy_1 = path coefficient of X_1 with respect to Y

ρy_3 = path coefficient of X_3 with respect to Y

ε_1, ε_2 = residual variables

Significance level $\alpha = 0.05$

Decision-making criteria:

If p-value < 0.05, then H_0 is rejected (there is a significant effect). If the p-value ≥ 0.05, then H_0 is accepted (there is no significant effect). Data analysis used SPSS version 25 software for descriptive analysis and path analysis (Adam Mappaompo et al., 2024)(Arga, 2025).

RESULTS AND DISCUSSION

Result

To obtain a general overview of the data of a study, descriptive data analysis was used on the data on the influence of arm muscle strength, forward torso flexibility and wrist flexibility on smash ability in badminton extracurricular students at the UPT SPF SDI Unggulan BTN Pemda.

Table 1.
Results of Descriptive Analysis of Data on the Effect of Arm Muscle Strength, Forward Trunk Flexibility, and Wrist Flexibility on Smashing Ability in Badminton Extracurricular Students at the UPT SPF SDI Unggulan BTN Pemda

Variabel	N	Range	Minimum	Maximum	Sum	Mean	Std. Deviation
Arm Muscle Strength	20	8.00	8.00	16.00	239.00	11.9500	2.39462
Front Toe Flexibility	20	9.00	10.00	19.00	287.00	14.3500	2.97843
Wrist Flexibility	20	5.00	8.00	13.00	212.00	10.6000	1.75919
Smashing Ability	20	5.00	4.00	9.00	134.00	6.7000	1.30182

Based on the table above, the following is a more detailed explanation:

1. Arm Muscle Strength: The descriptive analysis results show that the arm muscle strength of 20 extracurricular badminton students had a score range of 8, with a minimum score of 8 and a maximum score of 16. The total score was 239, with a mean of 11.95 and a standard deviation of 2.39462.
2. Forward Torso Flexibility: Forward torso flexibility, the score range was 9, with a minimum score of 10 and a maximum score of 19. The total score reached 287 with a mean score of 14.35 and a standard deviation of 2.97843.
3. Wrist Flexibility: The wrist flexibility variable had a score range of 5, with a minimum score of 8 and a maximum score of 13. The total score was 212 with a mean of 10.6 and a standard deviation of 1.75919.
4. Smashing Ability: Descriptive analysis of smashing ability showed a score range of 5, with the lowest score being 4 and the highest being 9. The total score for all respondents was 134, with an average of 6.7 and a standard deviation of 1.30182.

Table 2.
Data Normality Test Results: Variables: The Effect of Arm Muscle Strength, Forward Trunk Flexibility, and Wrist Flexibility on Smashing Ability in Badminton Extracurricular Students at the UPT SPF SDI Unggulan BTN Pemda

Variable	Shapiro-Wilk		
	Statistic	df	Sig.
Arm Muscle Strength	.957	20	.487
Front Toe Flexibility	.937	20	.212
Wrist Flexibility	.912	20	.071
Smashing Ability	.940	20	.238

Based on the table above, the following is a more detailed explanation:

1. Arm Muscle Strength: The results of the normality test for the arm muscle strength variable showed a significance value of 0.487. Both significance values are greater than $\alpha = 0.05$, so it can be concluded that the arm muscle strength data are normally distributed.
2. Forward Torso Flexibility: For the forward torso flexibility variable, the significance value was 0.212. Because both significance values were greater than 0.05, the forward torso flexibility data were also normally distributed.

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3. Wrist Flexibility: For the wrist flexibility variable, the Kolmogorov-Smirnov test showed a significance value of 0.071. The significance values for both tests were greater than 0.05, so it can be concluded that the wrist flexibility data were normally distributed.
4. Smashing Ability: The results of the normality test for smashing ability showed a significance value of 0.238. Therefore, the smashing ability data were also normally distributed.

Table 3.
Results of the Linearity Test of Data on the Effect of Arm Muscle Strength, Forward Trunk Flexibility, and Wrist Flexibility on Smashing Ability in Badminton Extracurricular Students at the UPT SPF SDI Unggulan BTN Pemda

Variabel	N	Nilai F	Sig.
X1 Ke Y	20	3.589	0.129
X2 Ke Y	20	0.561	0.788
X3 Ke Y	20	0.389	0.813
X1 Ke X3	20	0.647	0.711
X2 Ke X3	20	2.758	0.268

Based on the results of the linearity test for all variable relationships, both between the independent variables and the dependent variable and between independent variables, a significance value above 0.05 was obtained. Therefore, it can be concluded that all relationships are linear and meet the requirements for proceeding to simple and multiple regression analysis. These results support the research model's assumption that arm muscle strength, forward trunk flexibility, and wrist flexibility can be used to linearly predict the smashing ability of extracurricular badminton students.

Hypothesis Testing

Because the data in this study followed a normal distribution, parametric statistical analysis using regression techniques was used to test the research hypothesis.

Table 4.
Results of the regression test on the effect of arm muscle strength, forward trunk flexibility, and wrist flexibility on smashing ability in extracurricular badminton students at the UPT SPF SDI Unggulan BTN Pemda

Variabel	N	R Square	Nilai T Hitung	Sig.
X1 Ke Y	20	0.962	6.134	0.000
X2 Ke Y	20	0.962	2.127	0.004
X3 Ke Y	20	0.962	0.633	0.003
X1 Ke X3	20	0.965	3.049	0.007
X2 Ke X3	20	0.965	3.455	0.003

The following are the narrative analysis results in Table 4 above:

1. The Effect of Arm Muscle Strength (X_1) on Smashing Ability (Y): The regression test results showed an R-square value of 0.962, meaning that 96.2% of the variation in smashing ability can be explained by arm muscle strength. The calculated t-value was 6.134 with a significance level of 0.000, which is significantly less than 0.05. This indicates that arm muscle strength has a positive and significant effect on smashing ability. This means that the better a student's arm muscle strength, the more optimal their smashing ability.

2. The Effect of Forward Trunk Flexibility (X_2) on Smashing Ability (Y): A simple regression test on forward trunk flexibility also yielded an R-square value of 0.962, meaning that forward trunk flexibility explains 96.2% of the variation in smashing ability. The calculated t-value of 2.127 with a significance level of 0.004 indicates that the effect of forward trunk flexibility on smash ability is significant, as the significance level is less than 0.05. This indicates that the better a student's forward trunk flexibility, the more it supports body movements to produce a powerful smash.
3. The Effect of Wrist Flexibility (X_3) on Smash Ability (Y): The results of a simple regression test between wrist flexibility and smash ability also showed an R-square value of 0.962, meaning wrist flexibility explains 96.2% of the variation in smash ability. The calculated t-value of 0.633 with a significance level of 0.003 indicates that the effect is also significant. Although the calculated t-value is smaller than the other variables, the resulting significance level below 0.05 confirms that wrist flexibility still contributes significantly to supporting optimal smash technique.
4. Relationship between Arm Muscle Strength (X_1) and Wrist Flexibility (X_3): The regression test results showed an R Square value of 0.965, meaning that 96.5% of the variation in wrist flexibility can be explained by arm muscle strength. The calculated t value of 3.049 with a significance of 0.007 indicates that there is a significant influence between arm muscle strength and wrist flexibility. This can be interpreted as meaning that students with good arm muscles tend to have more optimal wrist control in performing smash movements.
5. Relationship between Forward Trunk Flexibility (X_2) and Wrist Flexibility (X_3): The relationship between forward trunk flexibility and wrist flexibility was also tested, with an R Square value of 0.965. This means that 96.5% of the variation in wrist flexibility can be explained by forward trunk flexibility. The calculated t value of 3.455 with a significance of 0.003 indicates that the relationship between the two is significant. This means that flexibility in the torso supports wrist coordination, thereby helping to increase the effectiveness of the smash technique.

Discussion

The results of this study indicate that arm muscle strength, forward trunk flexibility, and wrist flexibility significantly influence smashing ability in extracurricular badminton students. This finding aligns with various theories and previous research findings and adds to the current literature on physical factors that support badminton technical skills.

Arm Muscle Strength as a Key Factor in Smashing Technique: Regression results indicate that arm muscle strength significantly contributes to smashing ability. This can be explained by the biomechanics of motion theory proposed by Knudson (2021), which states that in racket sports like badminton, proximal muscle strength (shoulders, upper arms) plays a dominant role in generating maximum hitting power. Arm muscle strength supports the backswing, acceleration, and impact with the shuttlecock, resulting in fast

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and powerful smashes. Recent research by Ismail & Putra (2022) also confirms that smashing ability depends not only on technique but also on optimal arm muscle strength. Without adequate muscle strength, even the best technique will not be able to produce consistent speed and accuracy. Therefore, the results of this study emphasise the importance of a regular arm muscle strength training program for extracurricular badminton students.

The Role of Forward Trunk Flexibility in Supporting the Smash Movement: Forward trunk flexibility has also been shown to significantly influence smashing ability. This aligns with the chain of movement concept explained by McGinnis (2020) in his book, Biomechanics of Sport and Exercise, where trunk flexibility influences body rotation and the transfer of kinetic energy from the pelvis to the arms. An optimal smash movement requires a flexible trunk swing to support power transfer from the core muscles to the arms. Furthermore, these findings are reinforced by a recent study by Lee & Kim (2023), which found that trunk flexibility training increases the range of motion of lower back rotation and extension, which supports the efficiency of overhead shot techniques like the smash. Students with good trunk flexibility can maximise their swing angle, significantly increasing smash speed.

Wrist Flexibility as a Determinant of Smash Accuracy and Control: The study also showed that wrist flexibility contributes significantly to smashing ability. The latest theory from Zhang et al. (2022) on wrist biomechanics in racket sports explains that wrist flexibility allows athletes to perform proper pronation and supination as the shuttlecock strikes the racket. This movement determines the direction of the ball, placement accuracy, and speed variation of the smash. In modern badminton hitting techniques, variations in speed and angle of the shot are highly dependent on wrist flexibility and strength. (Chen & Wang, 2021) add that wrist control helps players execute deception shots, drop shots, and drive smashes more effectively. Therefore, mastering wrist flexibility is a crucial component that cannot be ignored in smash development.

The Relationship Between Physical Variables in Supporting Smashes. Interestingly, the results of this study also show a significant relationship between arm muscle strength and wrist flexibility, as well as between forward trunk flexibility and wrist flexibility. This supports the kinetic chain theory, where each body segment is interconnected to produce efficient and powerful movements. In line with the view (Kibler et al., 2019), the synergy between proximal muscle strength (shoulder and upper arm) and distal flexibility (wrist) is crucial for producing precise finishing movements. If one component is weak or stiff, energy will not be channelled optimally, resulting in a suboptimal smash technique. Therefore, physical development for badminton students should be carried out in an integrated manner: training strength, increasing trunk flexibility, and optimising wrist mobility.

Practical Implications and Directions for Training Development: Based on the results of this study, physical education teachers, extracurricular coaches, and parents need to understand that developing smashing skills is not sufficient to focus solely on technique. Structured physical training programs, such as arm muscle strengthening exercises (push-ups, pull-ups, resistance band training), trunk flexibility exercises (sit and reach, back extension), and wrist mobility exercises (wrist curls, wrist rotation), should be part of the training curriculum. In line with the Long-Term Athlete Development (LTAD) approach recommended by Lloyd et al. (2021), the integration of multicomponent physical training from elementary school age will build a strong physical foundation, support technical skills, and prevent the risk of injury due to muscle imbalances or joint stiffness.

The results of this study confirm that arm muscle strength, forward trunk flexibility, and wrist flexibility contribute significantly to developing badminton students' smashing abilities. This reinforces modern sports biomechanics theory and opens up opportunities for the development of more targeted physical training programs at the elementary school level. Thus, badminton coaching not only emphasises mastery of technique, but must also be supported by measurable physical condition coaching, so that each student has optimal technical performance according to their physical potential.

CONCLUSION

The conclusions of this study on extracurricular students at the UPT SPF SDI Unggulan BTN Pemda are as follows:

1. There is a direct effect of arm muscle strength on smashing ability in badminton extracurricular activities, with a percentage of 96.2%.
2. There is an effect of forward trunk flexibility on smashing ability in badminton extracurricular activities, with a percentage of 96.2%.
3. There is an effect of wrist flexibility on smashing ability in badminton extracurricular activities, with a percentage of 96.2%.
4. There is a direct effect of arm muscle strength on wrist flexibility in badminton extracurricular activities, with a percentage of 96.5%.
5. There is a direct effect of forward trunk flexibility on wrist flexibility in badminton extracurricular activities, with a percentage of 96.5%.

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