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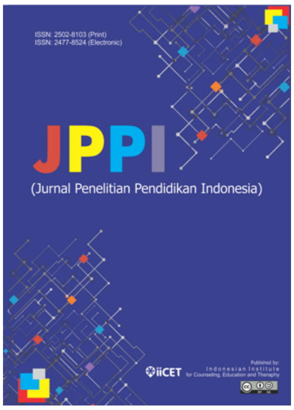

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Effects of arm explosive power, hand–eye coordination, and concentration on students' badminton skills

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ABSTRACT

This study aims to examine the influence of arm muscle explosive power, hand–eye coordination, and training concentration on badminton playing skills among elementary school students. A quantitative approach with path analysis was employed to analyze both direct and simultaneous relationships among variables. The sample consisted of 30 male students aged 10–12 years selected through purposive sampling. Data were collected using performance-based tests and standardized instruments, including a medicine ball throw test, shuttlecock wall toss test, grid concentration test, and badminton skill tests (service, lob, and smash). The results showed that arm muscle explosive power ($\beta = 0.664$; $p < 0.001$), hand–eye coordination ($\beta = 0.234$; $p = 0.045$), and training concentration ($\beta = 0.269$; $p = 0.023$) had significant positive effects on badminton skills. Simultaneously, these variables explained 70.6% of performance variance ($R^2 = 0.706$). In conclusion, badminton performance is influenced by integrated physical, coordinative, and psychological factors, with explosive power as the dominant predictor.

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Introduction

Badminton is recognized as a complex sport that demands not only technical mastery but also the integration of multiple performance components, including physical capacity, motor coordination, and psychological readiness. Unlike many other racket sports, badminton requires players to respond to high-speed shuttlecock movements with precision and efficiency within very limited time intervals. This dynamic nature makes badminton performance highly dependent on the interaction between neuromuscular control, perceptual ability, and decision-making processes (Rajab et al., 2025; Shapie et al., 2023). Therefore, understanding the determinants of performance in badminton requires a multidimensional perspective that goes beyond isolated skill analysis.

From a physiological standpoint, physical components play a foundational role in supporting badminton performance. Among these, arm muscle explosive power is particularly important, as it directly contributes to the generation of force in key techniques such as smash, clear, and drive.

Explosive power, defined as the ability to produce maximal force in minimal time, is closely associated with stroke velocity and effectiveness. Previous studies have reported that higher levels of upper limb explosive power significantly enhance the quality of offensive play, particularly in high-intensity rallies (Ochor & Amasiatu, 2025; Triansyah et al., 2023). However, the extent to which this component interacts with other performance factors remains insufficiently explored.

In addition to physical strength, coordinative abilities especially hand–eye coordination are essential in badminton due to the continuous interaction between perception and action. Players must rapidly process visual stimuli and translate them into precise motor responses, ensuring accurate shuttlecock placement and timing. This perceptual-motor synchronization is crucial for maintaining consistency in technical execution, particularly under competitive pressure (X. Chen et al., 2025; C. Zeng et al., 2025). Several studies have emphasized that coordination significantly influences skill acquisition and performance stability in racket sports (Abbasi et al., 2025; Wang et al., 2025).

Psychological factors also contribute significantly to sports performance, particularly in high-speed and cognitively demanding games like badminton. Concentration, as a key component of attentional control, enables athletes to focus on relevant stimuli while filtering out distractions. In the context of badminton, concentration supports rapid decision-making, anticipation of opponent movements, and error minimization during play. Empirical findings suggest that athletes with higher levels of concentration tend to demonstrate greater consistency and accuracy in performance outcomes (Ochor & Amasiatu, 2025; Triansyah et al., 2023).

Despite the recognized importance of these individual components, recent research has begun to highlight the need for a more integrative approach in understanding sports performance. Studies have shown that physical condition and concentration can jointly influence technical execution, particularly in skills such as serving and stroke accuracy (Ren et al., 2025; W. Zeng et al., 2025). Furthermore, other investigations indicate that badminton performance is shaped by the interaction of multiple factors, including strength, coordination, and mental readiness, rather than a single dominant variable (Mangun & Subarkah, 2024; Pratama, 2020).

However, most previous studies have tended to examine these variables in isolation or in limited combinations, resulting in a fragmented understanding of performance determinants (Aguzzi et al., 2024; Wu et al., 2025). This lack of integrative analysis limits the ability to fully capture the complexity of badminton performance, particularly when considering the dynamic interaction between physical, coordinative, and psychological domains. Consequently, there is a need for research that simultaneously investigates these variables within a unified analytical framework.

Another critical limitation in the existing literature is the population focus. The majority of studies have concentrated on elite or adolescent athletes, while research involving elementary school students remains relatively limited (Nisa'Urizka Fayogi et al., 2025; Saleh et al., 2024). This gap is important because children at the elementary level are in a crucial stage of motor and cognitive development, where foundational skills are formed and refined. Understanding performance determinants at this stage is essential for developing effective and age-appropriate training interventions.

From a theoretical perspective, sports performance can be understood as the result of an integrated system involving physical capacity, motor coordination, and psychological readiness. These components interact dynamically, where physical ability provides the foundation, coordination ensures efficient execution, and psychological factors regulate consistency and focus. This integrated framework aligns with contemporary sport science theories that emphasize a holistic approach to athlete development rather than isolated training components (Edmizal et al., 2023; Rahayu et al., 2024).

Methodologically, the complexity of these relationships requires an analytical approach capable of capturing both direct and indirect effects among variables. Path analysis offers a suitable framework for modeling such relationships, as it allows for the examination of structural interactions within a multivariate system. Despite its potential, the application of path analysis in the context of badminton performance, particularly among young athletes, remains limited in the literature.

Based on these gaps, this study aims to examine the influence of arm muscle explosive power, hand–eye coordination, and training concentration on badminton playing skills among elementary school students using a path analysis approach. The study specifically investigates both the individual and combined contributions of these variables in explaining performance outcomes.

The novelty of this research lies in its integrative and model-based approach, combining physical, coordinative, and psychological factors within a single analytical framework. In addition, this study focuses on elementary school athletes, a population that has received limited attention in previous research. The findings are expected to contribute not only to the theoretical understanding of sport performance but also to the development of more effective training strategies and coaching practices at the grassroots level.

Method

This study employed a quantitative cross-sectional design to examine the direct and simultaneous effects of arm muscle explosive power, hand–eye coordination, and training concentration on badminton playing skills. A regression-based path analysis approach was applied to model the relationships among variables, focusing on direct effects in line with the research objectives and empirical findings. The study was conducted during the 2025/2026 academic year at SD Negeri 12 Padang Kubu.

The population consisted of students participating in extracurricular badminton activities. A purposive sampling technique was used to select 30 male students aged 10–12 years who met specific inclusion criteria, including active participation in regular training (at least twice per week), good physical health, and recommendation from the physical education teacher. This sampling strategy was intended to ensure that participants had sufficient exposure to badminton training, although it may limit the generalizability of the findings.

Data were collected using standardized and commonly used instruments in sport performance research. Arm muscle explosive power was measured using the one-hand medicine ball throw test, with the best result from three trials recorded as the final score. Hand–eye coordination was assessed using a shuttlecock wall toss test, where participants performed repeated racket strikes within a fixed duration, and the total number of successful hits was recorded. Training concentration was measured using a grid concentration test adapted for children aged 10–12 years, assessing attention and focus through sequential number identification. Badminton playing skills were evaluated using performance-based tests consisting of service, lob, and smash techniques, with scores based on accuracy and consistency of execution.

To ensure data quality, all instruments were selected based on prior studies demonstrating acceptable levels of validity and reliability. The assessment of badminton skills was conducted using a structured scoring rubric and evaluated by trained assessors to reduce subjectivity. All testing procedures were standardized, including uniform instructions, warm-up sessions, and controlled testing conditions to minimize external influences.

Data analysis was performed using SPSS software. Prior to hypothesis testing, classical assumption tests were conducted, including normality (Kolmogorov-Smirnov test), linearity (deviation from linearity test), multicollinearity (tolerance and Variance Inflation Factor/VIF), and heteroscedasticity (Glejser test). Hypothesis testing was carried out using multiple regression analysis to examine both partial (t-test) and simultaneous (F-test) effects of the independent variables on badminton playing skills. The coefficient of determination (R^2) was used to determine the proportion of variance explained by the model. This analytical approach allowed for a clear evaluation of the contributions of physical, coordinative, and psychological factors to badminton performance, consistent with the findings reported in the results section.

Results and Discussions

The results of this study present a comprehensive analysis of the relationships between arm muscle explosive power, hand–eye coordination, and training concentration with badminton playing skills among elementary school students participating in extracurricular activities. The analysis begins with descriptive statistics to illustrate the general characteristics of the data, followed by prerequisite tests to ensure that the assumptions for regression analysis are satisfied. Subsequently, multiple regression analysis is conducted to examine both the individual and simultaneous contributions of the independent variables to badminton performance. Overall, the findings provide empirical evidence that integrates physical, coordinative, and psychological components as key determinants in the development of badminton playing skills.

Table 1. Descriptive Statistics of Research Variables

Variable	N	Min	Max	Mean	Std. Deviation
Arm Muscle Explosive Power (X1)	30	5.80	6.45	6.04	0.17
Hand–Eye Coordination (X2)	30	18	22	19.70	1.21
Training Concentration (X3)	30	16	21	18.63	1.43
Badminton Playing Skills (Y)	30	22	26	23.43	1.04

The descriptive analysis indicates that all variables exhibit relatively good average values with low to moderate variability, suggesting homogeneity among participants. Arm muscle explosive power shows the smallest standard deviation (SD = 0.17), indicating consistent physical performance across subjects. Meanwhile, training concentration presents the highest variability (SD = 1.43), reflecting differences in psychological engagement during training. Overall, badminton playing skills demonstrate a high mean score (M = 23.43), suggesting that the participants possess adequate technical competence. These findings confirm that the sample has a balanced profile across physical, coordinative, and psychological domains, providing a solid basis for further inferential analysis.

Table 2. Assumption Testing Results

Test	Indicator	Result	Decision
Normality	Sig. > 0.05	> 0.05	Normal distribution
Linearity (X1→Y)	Sig.	0.414	Linear
Linearity (X2→Y)	Sig.	0.081	Linear
Linearity (X3→Y)	Sig.	0.350	Linear
Multicollinearity	Tolerance > 0.1; VIF < 10	Fulfilled	No multicollinearity
Heteroscedasticity	Sig. > 0.05	X1 = 0.898; X2 = 0.252; X3 = 0.281	Homoscedastic

The prerequisite tests confirm that the dataset meets all classical assumptions required for multiple regression analysis. The normality test demonstrates that residuals are normally distributed, ensuring unbiased parameter estimation. Linearity tests reveal that all independent variables have linear relationships with the dependent variable, supporting the use of linear modeling. Additionally, the absence of multicollinearity indicates that each predictor contributes uniquely to the model without redundancy. The heteroscedasticity test further confirms the homogeneity of residual variance. Collectively, these results validate the robustness and statistical adequacy of the regression model for hypothesis testing.

Table 3. Multiple Regression and Hypothesis Testing Results

Variable	β	Sig.	Interpretation
X1 → Y	0.664	< 0.001	Significant positive effect
X2 → Y	0.234	0.045	Significant positive effect
X3 → Y	0.269	0.023	Significant positive effect

The regression analysis reveals a strong relationship between the independent variables and badminton playing skills (R = 0.840). The coefficient of determination ($R^2 = 0.706$) indicates that 70.6% of the variance in badminton performance is explained by arm muscle explosive power, hand–eye coordination, and training concentration. Among the predictors, arm muscle explosive power ($\beta = 0.664$) emerges as the most dominant factor, highlighting the critical role of physical capacity in performance. Hand–eye coordination and training concentration also contribute significantly, emphasizing the importance of both motor coordination and psychological readiness. The F-test confirms that the model is statistically significant, demonstrating that the predictors collectively influence badminton skills. However, the non-significant relationship between hand–eye coordination and training concentration suggests that no mediating effect occurs, reinforcing the direct contribution model identified in the path analysis.

This study provides empirical evidence that badminton playing skills among elementary school students are influenced by an integrated set of physical, coordinative, and psychological factors. Rather than functioning independently, these components contribute collectively to performance outcomes, reflecting the multidimensional nature of sport performance (Al-selmi et al., 2024; Syukron et al., 2026). From a theoretical perspective, this finding supports the notion that athletic performance emerges from the interaction between neuromuscular capacity, perceptual-motor processes, and cognitive control, particularly in dynamic and high-speed sports such as badminton.

Among the examined variables, arm muscle explosive power demonstrated the strongest contribution to badminton playing skills, indicating its critical role in determining performance quality. This can be explained through biomechanical and physiological mechanisms, where explosive power enables athletes to generate high force in a short time, directly influencing shuttlecock speed and stroke effectiveness in techniques such as smash, clear, and drive (DeCouto et al., 2024; Mainer-Pardos et al., 2024). In the context of young athletes, this finding suggests that physical capacity serves as a fundamental base for skill execution, although its development must be aligned with age-appropriate training principles. This result is consistent with previous studies emphasizing that inadequate physical conditioning may limit the efficiency of technical skill performance (Alsaudi, 2020; Winata et al., 2021).

Hand–eye coordination was also found to significantly influence badminton performance, highlighting the importance of perceptual-motor integration in skill execution. In practical terms, coordination enables players to synchronize visual input with motor responses, allowing for accurate timing and shuttlecock placement during play. This process involves rapid information processing and motor adjustment, which are essential in responding to fast-moving objects in badminton (Y. Chen et al., 2024; de Jager et al., 2024). The findings reinforce the view that coordination functions as a bridge between physical capacity and technical execution, supporting performance consistency, particularly in situations that require precision and timing.

The role of training concentration further emphasizes the importance of psychological readiness in sports performance. Concentration, as a component of attentional control, allows athletes to maintain focus on relevant stimuli while minimizing distractions, which is crucial in high-intensity game situations. The results indicate that students with higher levels of concentration tend to perform more consistently and make fewer technical errors. This aligns with theoretical perspectives suggesting that cognitive factors such as attention and focus are essential for optimizing motor performance and decision-making processes (Guo et al., 2025; S. Li et al., 2024). However, the relatively smaller contribution of concentration compared to physical variables suggests that psychological factors may act as supporting components rather than primary determinants in early-stage athletes.

Interestingly, the analysis revealed that hand–eye coordination does not significantly influence training concentration, indicating that these variables operate through different underlying mechanisms. While coordination is primarily associated with neuromuscular and sensorimotor processes, concentration is influenced by cognitive and emotional factors such as motivation, fatigue, and environmental conditions (Ghaffar et al., 2025; Weijer et al., 2024). This finding suggests that improvements in motor abilities do not necessarily translate into enhanced psychological readiness, highlighting the need for separate and targeted training approaches for each domain.

The combined effect of arm muscle explosive power, hand–eye coordination, and training concentration explains a substantial proportion of variance in badminton playing skills (70.6%), indicating that performance is shaped by the interaction of multiple components rather than a single dominant factor. However, given the relatively small sample size, this high explanatory value should be interpreted cautiously, as it may reflect model overestimation. Additionally, other important variables such as agility, lower-body strength, and training experience were not included in the model, which may account for the remaining unexplained variance (N.M. et al., 2024; The Lancet Regional Health – Western Pacific, 2024). These limitations highlight the need for further research incorporating a broader range of performance determinants.

From a practical standpoint, the findings suggest that badminton training programs for elementary school students should adopt a holistic approach that integrates physical conditioning, coordination training, and psychological development. Training interventions may include plyometric exercises to enhance explosive power, coordination drills to improve perceptual-motor integration, and cognitive training strategies to strengthen concentration and attentional control (F.-Y. Chen et al., 2025; Z. Li et al., 2025; Mueller et al., 2024). Future research is recommended to employ longitudinal designs and larger samples to better understand the developmental dynamics of badminton performance and to validate the findings across different populations.

Conclusions

The findings of this study conclude that arm muscle explosive power, hand–eye coordination, and training concentration have significant positive effects, both individually and simultaneously, on badminton playing skills among elementary school students, with explosive power emerging as the most dominant factor; therefore, the development of badminton performance requires an integrated training approach that balances physical, coordinative, and psychological components.

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