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Physical and Cognitive Predictors of Badminton Short Serve Mastery in High School

Nur Najemunnisa [1], Ahmad Adil[2], Andi Ridwan[3]
[1, 2, 3] Department of Physical Education and Sport, Universitas Negeri Makassar, Indonesia

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ABSTRACT

Mastery of open-motor skills like the badminton short serve is often hindered by an incomplete understanding of cognitive-motor interactions. This study evaluated physical (arm muscle strength, X1; hand–eye coordination, X2) and cognitive (concentration, Y) predictors of badminton short serve mastery (Z) among high school student-athletes (N=25, aged 15–17), positioning concentration as a mediator. Utilizing a quantitative explanatory correlational design, data were collected via validated field tests and analyzed using path analysis. The empirical model accounted for 58.8% of the total variance in serving proficiency. Arm muscle strength acted as a dominant predictor, exerting significant direct effects on concentration (beta = 0.514, $p < 0.05$) and short serve mastery (beta = 0.421, $p < 0.05$). Sobel tests confirmed that concentration significantly and partially mediated the relationship between arm strength and serving performance ($Z = 1.978$, $p = 0.047$), amplifying the total integrative effect to 0.659, alongside its own direct impact on mastery (beta = 0.463, $p < 0.05$). Conversely, hand–eye coordination yielded no significant direct or indirect effects ($p > 0.05$). These findings demonstrate that technical mastery relies on both biomechanical readiness and cognitive control, where upper-body strength underpins the cognitive stability required for precise execution. Consequently, sports pedagogy should integrate targeted physical conditioning with structured cognitive training.

Corresponding Author:

Nur Najemunnisar,
Department of Physical Education and Sport, Universitas Negeri Makassar, Indonesia
Email: nurnajemunnisa240402@gmail.com

1. INTRODUCTION

In the physical education, sports, and health (PJOK) curriculum and extracurricular programs at the high school level, badminton is a very popular net sport (Amri, 2025; Kurniawan et al., 2022). One of the essential skills determining success in the game is the short serve (Iino et al., 2025; Vial et al., 2019). The short serve in badminton is categorized as a complex open-motor skill because it demands high accuracy, biomechanical precision, and mental stability, considering that the shuttlecock must pass over the thinnest possible net to limit the opponent's attack opportunities

(Abedanzadeh et al., 2022; Duncan et al., 2017). At the high school level, mastery of the short serve is not merely a technical achievement but rather a reflection of the success of the sports pedagogy process in developing students' physical coordination and cognitive readiness (Portillo et al., 2023).

However, the reality on the ground shows that many high school students, including those in extracurricular programs or student-athletes, still experience significant difficulty consistently executing a perfect short serve. Common failures include the shuttlecock getting stuck in the net, bouncing too high, or going out of bounds. Physical education teachers and extracurricular coaches often assume that this failure is solely due to a lack of technical drill repetition (Jayantilal & O'Leary, 2017; Portillo et al., 2023). As a result, learning interventions tend to be monotonous and ignore students' inherent internal factors, both physical (motor) and cognitive (psychological).

Theoretically, precise serve execution is driven by several dominant factors. First, from a physical perspective, arm muscle strength plays a crucial role in providing stability to the shoulder and wrist joints during a smooth push on the shuttlecock. Second, eye-hand coordination serves as the motor foundation for aligning visual perception (seeing the position of the shuttlecock and net) with the hand's motor response at impact (Rajab et al., 2025). In addition to physical factors, the task demands of badminton also require strong cognitive aspects, particularly concentration. Concentration acts as a cognitive filter that eliminates environmental distractions (such as mental pressure or crowd noise) so that students maintain their focus on the serve target (Abedanzadeh et al., 2022; Saleh et al., 2024).

Although the relationship between muscle strength, coordination, and concentration on sports performance has been extensively researched, most previous studies have focused on elite-level professional athletes or youth badminton clubs (Pompa et al., 2024; Rajab et al., 2025; Suchomel et al., 2016). There is a dearth of literature examining the interaction of these variables within sports pedagogy at the secondary school level. More specifically, the mechanism by which concentration acts as a mediating variable—linking physical readiness (arm muscle strength and eye-hand coordination) to the outcome of short serve technique mastery—has not been comprehensively explored in a high school student population.

The scientific novelty of this research lies in its integrative approach, which connects physical (biomechanical) and cognitive (psychological) predictors in a single path analysis model, positioning concentration as a mediating variable in a population of high school students. This research shifts from conventional research trends that examine physical variables in isolation. Through this model, this study reveals the extent to which students' physical strength requires cognitive control to produce optimal short serve mastery in the context of school sports.

Based on this gap, this study aims to analyze the direct influence of arm muscle strength and hand-eye coordination on short serve mastery in high school students, as well as the indirect influence of these two physical variables through concentration as a mediating variable. The results of this study are expected to provide theoretical contributions to the development of sports pedagogy and practical contributions for

physical and health education teachers in developing training curricula based on integrated physical-cognitive training.

2. METHOD

This study employed a quantitative approach with an explanatory correlational design. This design was chosen to empirically test the causal relationships and predictive contributions of independent variables to the dependent variable, both directly and indirectly through mediating variables. In this study, arm muscle strength (X1) and hand-eye coordination (X2) were positioned as physical predictors (exogenous variables), concentration (Y) as a cognitive predictor and mediating variable (endogenous-intervening), and badminton short serve mastery (Z) as the final dependent variable (endogenous-dependent). This approach allowed the researcher to comprehensively map the structure of relationships between variables within the context of sports pedagogy.

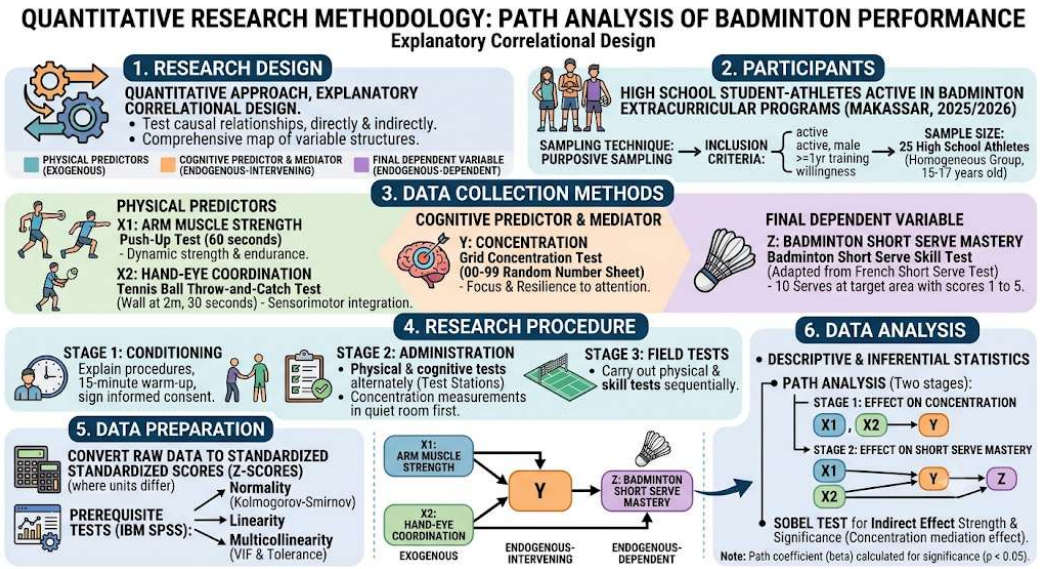

Figure 1. Research Flowchart

The population in this study was all high school students active in extracurricular badminton programs in Makassar City during the 2025/2026 academic year. Sampling was conducted using a purposive sampling technique based on strict inclusion criteria: (1) active high school students, (2) male, (3) at least one year of training, and (4) willingness to fully participate in all physical and cognitive tests. Based on these criteria, a homogeneous sample of 25 high school student-athletes aged 15–17 was obtained. This sample size was deemed representative and met the minimum adequacy requirements for path analysis in specific sports groups at school.

Data collection for physical predictors was conducted through two standardized field tests. First, arm muscle strength (X1) was measured using the Push-Up Test for 60 seconds to assess the endurance and dynamic strength of the students' upper extremity

muscles. Second, eye-hand coordination (X2) was measured using the Tennis Ball Throw-and-Catch Test facing a wall at 2 meters for 30 seconds. This coordination test aims to evaluate students' sensorimotor integration abilities in responding to fast-moving visual objects, which represent the biomechanical characteristics of hitting a shot in badminton.

To measure cognitive predictors, researchers used the Grid Concentration Test, a sports psychology instrument based on a random number sheet (00-99). Students were asked to locate and cross out numbers sequentially within 90 seconds under control conditions to assess their level of focus and resilience to selective attention. Meanwhile, the dependent variable, badminton short serve mastery (Z), was measured using the Badminton Short Serve Skill Test, adapted from the French Short Serve Test. In this test, students executed 10 serves at a target area with an objective value (score 1 to 5) placed in front of the opponent's court.

The research procedure was carried out in three main stages under the close supervision of researchers and senior physical education teachers to ensure ecological validity. The first stage was conditioning, in which all students explained the test procedure, underwent a structured 15-minute warm-up, and signed informed consent. The second stage was the administration of physical and cognitive tests, conducted alternately (test stations) to avoid the effects of accumulative fatigue. Concentration measurements were conducted in a quiet, dedicated room before students were taken to the sports field to undergo arm muscle strength and hand-eye coordination tests, concluding with a short serve ability test.

Before testing the main hypothesis, all raw data obtained was converted into standardized scores (Z-scores) if there were differences in measurement units. Next, a series of statistical prerequisite tests were conducted using IBM SPSS software. These prerequisite tests included: (1) a normality test using the Kolmogorov-Smirnov technique to ensure the data were normally distributed; (2) a linearity test to assess the linearity of relationships between variables; and (3) a multicollinearity test using the Variance Inflation Factor (VIF) and Tolerance values to ensure there were no extreme correlations between predictors that could undermine the regression model.

The final data analysis was conducted using descriptive and inferential statistics in the form of Path Analysis. This path analysis was broken down into two stages of structural equations: first, testing the effect of arm muscle strength and hand-eye coordination on concentration; second, testing the effect of arm muscle strength, hand-eye coordination, and concentration on short serve mastery. The path coefficient (beta) was calculated to determine the significance of the direct effect ($p < 0.05$). Furthermore, to test the strength and significance of the indirect effect (the concentration mediation effect), the researcher used the Sobel Test by calculating the standard error value of the product of the path coefficients of the exogenous variable to the mediator and the mediator to the endogenous variable.

3. RESULTS AND DISCUSSION

Results

Descriptive Analysis of Research Data

Before testing the hypotheses, descriptive statistical analysis was conducted to provide a general overview of the data distribution from a sample of 25 high school students. The data included the minimum, maximum, mean, and standard deviation (SD) values for four variables: Arm Muscle Strength (X_1), Eye-Hand Coordination (X_2), Concentration (Y), and Short Serve Mastery (Z).

Table 1. Descriptive Statistical Analysis

Variables	Data Units	Min Value	Max Value	Mean	Standard Deviation (SD)
Arm Muscle Strength (X1)	Repetitions/Minute	22	41	31.44	5.12
Hand-Eye Coordination (X2)	Frequency/30 Seconds	14	26	19.88	3.37
Concentration (Y)	Grid Test Score	6	17	11.56	2.89
Short Serve Mastery (Z)	Cumulative Score	24	46	35.2	6.18

In general, the descriptive data showed an ideal level of variability in the high school student population studied. The average arm muscle strength of 31.44 repetitions indicates moderate to good upper extremity physical condition for adolescents, while the average short serve achievement (35.20) indicated quite varied technical abilities among the student-athletes.

Analysis Prerequisite Tests (Classical Assumptions)

Path analysis requires data to meet the assumptions of normality, linearity, and freedom from multicollinearity.

- Normality Test: Based on the Kolmogorov-Smirnov test, the significance value (p-value) for all variables is above 0.05 ($p = 0.200$ for X1; $p = 0.185$ for X2; $p = 0.200$ for Y; and $p = 0.142$ for Z). This proves that all data are normally distributed.
- Linearity Test: The results of the linearity test between exogenous and endogenous variables show that the Linearity Deviation from Linearity values are all > 0.05, indicating that all relationships between variables in the model are linear.
- Multicollinearity Test: The test showed a tolerance value between X1 and X2 of 0.812 (> 0.10) and a Variance Inflation Factor (VIF) of 1.231 (< 10). Therefore, it was concluded that there were no serious multicollinearity problems in the regression model.

Path Model Testing (Path Analysis)

The path analysis in this study was divided into two multiple linear regression equation structures to examine the direct influence of physical and cognitive predictors.

Sub-Structure 1: The Effect of X1 and X2 on the Mediating Variable, Concentration (Y). The first equation tests the extent to which two physical predictors are able to

predict the cognitive condition (concentration) of high school students. The parameter estimation results are presented in the following table:

Table 2. Path Analysis Results

Exogenous Variables	Path Coefficient (β)	t value	Significance (p)	Conclusion
Arm Muscle Strength (X1)	0.514	2.884	0.008	Significant (p<0.05)
Eye-Hand Coordination (X2)	0.145	0.814	0.424	Not Significant
R-Square (R2)	0.362			F-test = 6.241 (p=0.007)

The results of Sub-Structure 1 indicate that arm muscle strength has a positive and significant direct effect on concentration (beta = 0.514, $p < 0.05$). In contrast, eye-hand coordination did not show a significant direct effect on students' concentration levels (beta = 0.145, $p > 0.05$). The R^2 value of 0.362 indicates that the simultaneous contribution of arm muscle strength and eye-hand coordination in explaining the variance in concentration is 36.2%, while the remainder is driven by other factors outside the model.

Substructure 2: The Effect of X1, X2, and Y on Short Serve Mastery (Z)

The second equation tests the direct influence of all physical and cognitive predictors on the final target of mastering the short serve technique in badminton.

Table 3. Path Analysis

Exogenous Variables	Path Coefficient (β)	t value	Significance (p)	Conclusion
Arm Muscle Strength (X1)	0.421	2.492	0.021	Significant (p<0.05)
Eye-Hand Coordination (X2)	0.088	0.562	0.58	Not Significant
Concentration (Y)	0.463	2.711	0.013	Significant (p<0.05)
R-Square (R2)	0.588			F-test = 9.982 (p=0.000)

The data above confirm that Arm Muscle Strength (beta = 0.421, $p < 0.05$) and Concentration (beta = 0.463, $p < 0.05$) act as significant direct predictors of short serve mastery in high school students. Meanwhile, eye-hand coordination was again shown to have no statistically significant direct effect (beta = 0.088, $p > 0.05$). The total coefficient of determination (R^2) for this substructure reached 0.588, indicating that this model is able to explain 58.8% of the phenomenon of short serve mastery in badminton in high school students.

Indirect Effect Analysis and Mediation Test (Sobel Test)

To prove the novelty hypothesis regarding the role of concentration (Y) as a mediating variable between physical readiness and technique mastery, an indirect effect calculation was performed, and its strength was tested using the Sobel Test formula.

- The results of the first hypothesis test showed that concentration (Y) significantly acted as a partial mediator in the relationship between arm muscle strength (X1) and badminton short serve mastery (Z). Based on the structural analysis, arm muscle strength had a direct effect coefficient of 0.421 on service technique mastery. When the model included cognitive aspects, an indirect effect contribution through the concentration variable was found to be 0.238, obtained by multiplying the coefficients between paths (0.514 x 0.463). Consequently, the total integrative effect strength of physical readiness, supported by cognitive focus, increased substantially to 0.659.
- The importance of concentration's role as a mediator in this first path was empirically confirmed through Sobel Test calculations. The formal significance test results showed a Z-value of 1.978, which is above the critical threshold of 1.96 with a significance parameter of $p = 0.047$ ($p < 0.05$). This finding indicates a valid partial mediation mechanism, meaning that high school students' arm muscle strength not only dictates stroke accuracy mechanically and biomolecularly, but also contributes to building cognitive stability and mental focus before ultimately leading to mastery of precise serving.
- Conversely, a contrasting phenomenon was found in the second path test, where concentration did not show a significant mediating role in the relationship between eye-hand coordination (X2) and mastery of short serve (Z). The indirect effect coefficient formed in this path was recorded as very weak, at only 0.067 (0.145 x 0.463). This result was supported by the Sobel Test confirmation, which produced a Z-value of 0.782 with a significance level far beyond the tolerance limit ($p = 0.434 > 0.05$). Thus, it is concluded that for the population of high school students studied, fluctuations in cognitive focus ability do not bridge or influence the effectiveness of students' eye-hand coordination reflexes in executing short service techniques on the court.

Discussion

The Contribution of Arm Muscle Strength as a Predictor of Dominant Physique

The findings of this study indicate that arm muscle strength has a direct, positive, and significant effect on the mastery of the short badminton serve in high school students (beta = 0.421, p = 0.021). From a kinesiology and sports biomechanics perspective, the short serve is a fine motor skill that requires full control of the force to ensure the shuttlecock glides narrowly over the net (Song, 2026). Optimal arm muscle strength—particularly the deltoid, biceps brachii, triceps brachii, and wrist flexor muscles—acts as a stabilizer for the upper extremity joints. When a student has a strong foundation of arm muscle strength, they can dampen unnecessary kinetic vibrations during the backswing and impact phases. Conversely, students with weak muscle strength tend to experience micro-tremors in the wrist, which results in inaccurate racket-to-shuttlecock contact angles.

These results align with the principles of sports pedagogy, which state that developing structural physical fitness is an absolute prerequisite for students to master

complex technical skill patterns (Guo et al., 2026; Yu, 2025). At the high school level, student physical strength variability remains quite high due to the influence of different biological growth phases. This study demonstrates that repetitive drills will not yield optimal results without adequate biomotor capacity in the form of arm muscle strength. Therefore, arm muscle strengthening through measured bodyweight training, such as push-ups, must be integrated by physical education teachers as part of the general preparation phase of both the learning process and extracurricular activities.

The Central Role of Concentration as a Cognitive Mediator

The most crucial and novel phenomenon in this study is the evidence of concentration as a significant partial mediator in the relationship between arm muscle strength and short serve mastery (Z-value = 1.978, p = 0.047). The indirect effect coefficient of 0.238 confirms that the mechanical efficiency of students' physical strength requires a cognitive "filter" to produce precise technical performance. Psychomotorically, arm muscle strength provides a sense of internal security and energy efficiency, which then frees students' cognitive capacity from physical anxiety (Liang, 2025; Portaz et al., 2024). In other words, students who are physically fit tend to be more easily able to direct their full attention (selective attention) to the target serve, without being distracted by muscle fatigue or fear of motor failure.

Concentration acts as a regulator of rhythm and timing when executing short serves, which, according to Cognitive Load theory, serves to minimize extraneous cognitive load (school environment distractions such as peer cheers or assessment pressure). When arm muscle strength interacts simultaneously with a high level of concentration, the total effect on serve mastery increases dramatically, reaching 0.659. This finding provides a new direction for the sports pedagogy curriculum in secondary schools: the badminton learning process should no longer be designed in isolation between physical and mental training. Physical education teachers should begin implementing an integrated physical-cognitive training approach, for example, by training students to execute short serves immediately after intensive physical activity to develop concentration resilience under physical stress (Dhahbi et al., 2025).

Anomalies of Eye-Hand Coordination in a High School Student Population

An interesting and anomalous finding in this study is the insignificant direct or indirect effect of eye-hand coordination on mastery of the short badminton serve in a sample of high school students (beta = 0.088, p = 0.580; mediation effect p = 0.434). This finding appears to contradict some conventional literature that positions eye-hand coordination as a universal element in racket sports (Lijin, 2025). However, upon closer analysis based on task characteristics, the short badminton serve is a type of closed-motor skill that is self-paced—meaning the student determines when the movement begins, and the object (shuttlecock) is stationary in the student's hand before being struck.

This situation differs significantly from the situation of a smash or drive, which are externally paced, where a high level of eye-hand coordination is necessary to anticipate

the incoming ball from a dynamically moving opponent. At the developmental level of high school students (ages 15–17), basic sensorimotor coordination functions have generally reached the mature stage. As a result, variability in basic eye-hand coordination ability is no longer the primary differentiator in determining the success of a short serve. This research confirms that for high school students, the most crucial factor in a successful short serve technique is not basic visual-coordination reflexes but rather mechanical wrist stability (muscle strength) and mental attentional acuity (concentration) just before impact (Sitorus et al., 2025; Kasmad & Badaru, 2020).

Theoretically and practically, this research makes significant contributions to the development of sports pedagogy and the design of physical education (PJOK) curricula at the secondary school level. Academically, this article enriches the literature by confirming an integrative path analysis model, which demonstrates that high school students' mastery of fine motor skills is not solely driven by physical mechanics (arm muscle strength), but also requires the active involvement of cognitive control (concentration) as a mediating variable. In practical terms, these findings serve as an empirical guide for sports teachers and extracurricular coaches to shift the monotonous conventional learning paradigm—from initially relying solely on repetitive technical drills—towards the application of the physical-cognitive integrated training method that combines physical conditioning of the body with mental attention-strengthening training to produce student-athletes who have high performance accuracy on the field.

4. CONCLUSION

This study demonstrates that badminton short serve mastery among student-athletes is robustly predicted by an integration of physical capacity and cognitive control, with the final empirical model accounting for 58.8% of the total variance in serving proficiency. Path analysis reveals that arm muscle strength (X1) acts as a dominant predictor, exerting significant direct effects on both student concentration (beta = 0.514, $p < 0.05$) and short serve mastery (beta = 0.421, $p < 0.05$). Furthermore, Sobel test confirmation validates the pivotal role of concentration (Y) as a significant partial mediator between arm muscle strength and short serve execution (Z-value = 1.978, $p = 0.047$), effectively amplifying the total integrative effect of physical readiness and cognitive focus to 0.659, alongside its own substantial direct impact on serving mastery (beta = 0.463, $p < 0.05$). Conversely, eye-hand coordination (X2) yields no statistically significant direct or mediated influence on either concentration or short serve outcomes ($p > 0.05$). Ultimately, these findings conclude that high school badminton pedagogy should shift from purely mechanical training toward a holistic approach; arm muscle strength does not merely dictate stroke mechanics biomolecularly but also underpins the cognitive stability and mental focus required to execute highly precise technical skills on the court.

Based on these findings, future research and sports pedagogy should adopt a more holistic training matrix that deliberately integrates physical conditioning with cognitive enhancement, rather than relying on isolated mechanical drills. Specifically, badminton coaches and physical education teachers should prioritize targeted upper-extremity

resistance programs—such as high-intensity progressive push-up variations—not only to enhance biomomechanical power but also as a physiological foundation to stabilize student-athletes' mental focus and selective attention prior to serving. Additionally, given that eye-hand coordination did not significantly influence technical proficiency in this cohort, training regimens should shift valuable instructional time away from generic coordination drills toward specialized grid concentration exercises and situational pressure drills. Finally, to expand the ecological validity of these insights, future studies should investigate this path analysis model across larger, heterogeneous samples, incorporating advanced neurophysiological tracking (e.g., EEG or eye-tracking tech) to more precisely map the real-time cognitive-motor interplay during high-stakes competitive serving.

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