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Determinants of Badminton Technical Skills: Integrating Physical Conditioning and Motor Skills Through Structural Equation Modeling

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Abstract

Study purpose. Understanding the factors that influence technical skill development in badminton remains an important issue in sport science, as performance in racket sports is shaped by the interaction of physical and motor abilities. Addressing the complex determinants of badminton technical skills is the main objective of this study, which seeks to integrate physical conditioning and motor skills as foundational elements for performance. This study aimed to examine the structural relationship between physical conditioning, motor skills, and badminton basic skills using a Structural Equation Modeling (SEM) approach.

Materials and methods. The research employed a quantitative explanatory design involving 76 participants consisting of 57 males and 19 females. Physical conditioning was assessed through standardized physical fitness tests including leg strength, arm strength, endurance, speed, agility, power, flexibility, and balance. Motor skills were measured using the Test of Gross Motor Development-2 (TGMD-2) covering locomotor and object control skills, while badminton basic skills were evaluated through performance tests consisting of service, lob, smash, and wall volley. Data were analyzed using SEM with JASP to examine the relationships among latent variables.

Results. The results indicated that the proposed structural model demonstrated good model fit and revealed that physical conditioning and motor skills contribute to the development of badminton basic skills. These findings highlight the importance of integrating physical fitness and motor coordination in developing badminton technical skills.

Conclusions. The study implies that training and instructional programs should adopt an integrative approach that combines physical conditioning, motor skill development, and technical practice to optimize skill acquisition in badminton.

Keywords: Physical Conditioning, Motor Skills, Badminton Basic Skills, Structural Equation Modeling, Sport Performance.
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Introduction

Badminton is one of the most popular sports and is widely played across many countries (Mansur et al., 2020; Sumroti & Himawan, 2021). It belongs to the category of net games that require speed, movement coordination, stroke accuracy, and rapid decision-making during play. The fast and dynamic nature of badminton demands players to perform various explosive movements such as jumping, rapid changes of direction, and high-intensity strokes within relatively short periods (Damar et al., 2026; Fatma & Irawan, 2026). Given these characteristics, mastery of basic technical skills such as the serve, lob, smash, and wall volley becomes a crucial component in determining the effectiveness of badminton performance (Ma et al., 2024).

Technical skills in badminton are not solely influenced by technical ability, but are also affected by various supporting factors that interact with one another in shaping performance. One of the most fundamental factors is physical condition (PC) (Dameria et al., 2023; Deng et al., 2024; Jaworski & Zak, 2016; Nugroho et al., 2021). Physical condition reflects the body's ability to perform physical activities effectively and efficiently during a match (Ismoko & Putro, 2023). Components of physical condition such as strength, endurance, speed, agility, power, flexibility, and balance play a significant role in supporting athlete performance in dynamic sports (Shedge et al., 2024). In the context of badminton, lower-body strength contributes to jumping ability and rapid changes of direction (Isauraya et al., 2025), while upper-body strength and power are associated with the ability to produce strong and accurate strokes (Yuliawan, D. & FX Sugiyanto, 2014). Additionally, speed and agility are essential for player mobility in covering the court and reaching the shuttlecock effectively (Ananda & Rusdiawan, 2025).

Several studies have shown that components of physical condition have a significant relationship with performance in racket sports, including badminton (Arief & Wiriawan, 2022; Zhannisa et al., 2018). Athletes with better physical condition tend to maintain high playing intensity and produce more consistent stroke quality throughout the match (Arnando et al., 2024). Conversely, limitations in physical condition can lead to decreased effectiveness of technical movements, delayed responses to opponents' actions, and reduced stroke accuracy in dynamic game situations. This explanation clearly indicates that physical condition is a key determinant influencing the mastery of technical skills in badminton.

While physical condition is important, motor ability is also a fundamental factor in mastering sports skills (Hasan et al., 2024; Kusnandar et al., 2021). Motor ability refers to an individual's capacity to coordinate various body movements efficiently and in an integrated manner to produce optimal movement performance. In sports science, fundamental motor skills such as locomotor skills and object control are considered the foundation for the development of more complex sport-specific skills (Barnett et al., 2016). Locomotor skills are related to the ability to perform movements such as walking, running, jumping, and quickly changing positions. In badminton, locomotor skills are esse Locomotor skills are related to the ability to perform movements such as walking, running, jumping, and quickly changing positions. In badminton, locomotor skills are essential as players must move rapidly and efficiently to reach the shuttlecock in different areas of the court. Meanwhile, object control skills are associated with the ability to coordinate body movements with the use of equipment. In badminton, this involves coordination between body movements, racket handling, and interaction with the shuttlecock to produce accurate and well-directed strokes. Research indicates that individuals

with higher levels of motor competence tend to have greater ability to learn and master sports skills (McCoy, 2022). Therefore, motor ability not only serves as a foundation for developing technical skills but also contributes to improving movement efficiency during play.

Preliminary observations in the field revealed that many novice badminton players struggle to maintain stroke accuracy and consistency, often due to suboptimal movement coordination and difficulties in integrating physical capacity with fundamental motor actions during dynamic play**.** Initial as players must move rapidly and efficiently to reach the shuttlecock in different areas of the court. Meanwhile, object control skills are associated with the ability to coordinate body movements with the use of equipment. In badminton, this involves coordination between body movements, racket handling, and interaction with the shuttlecock to produce accurate and well-directed strokes. Preliminary observations in the field revealed that many novice badminton players struggle to maintain stroke accuracy and consistency, often due to suboptimal movement coordination and difficulties in integrating physical capacity with fundamental motor actions during dynamic play. Research indicates that individuals with higher levels of motor competence tend to have greater ability to learn and master sports skills (McCoy, 2022). Therefore, motor ability not only serves as a foundation for developing technical skills but also contributes to improving movement efficiency during play.

Although numerous studies have examined the influence of physical condition and motor ability on sports performance, most of these studies have been conducted partially, and thus have not fully explained the comprehensive relationships among the factors influencing sports skills. In fact, skill performance in sports is the result of complex interactions between physical and motor components that operate simultaneously during gameplay. In the context of badminton, studies that integrate physical conditioning and motor skills into a single analytical model to explain the mastery of basic skills remain relatively limited. Therefore, this study aims to analyze the relationship between physical conditioning and motor skills on basic skills in badminton using a Structural Equation Modeling (SEM) approach, in order to provide a more comprehensive understanding of the contribution of each factor in shaping badminton playing skills.

Materials and methods

Study participants

The study involved 76 participants (57 male, 19 female) from the Physical Education, Health, and Recreation Study Program (PJKR) at UN PGRI Kediri, Indonesia. Participants were selected using purposive sampling based on criteria such as basic badminton experience and the ability to complete all physical, motor, and technical skill tests. The sample size of 76 was considered sufficient for SEM analysis, provided the measurement model's validity and reliability requirements were met (Hair et al., 2021).

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Study organization

This study employed a quantitative approach with an explanatory research design to analyze the structural relationships among latent variables influencing basic badminton skills. The analysis was conducted using Structural Equation Modeling (SEM) to examine both direct and indirect relationships among variables simultaneously (Hair et al., 2021). The variables of physical conditioning and motor skills functioned as exogenous variables, while basic badminton skills served as the endogenous variable. This approach was selected because it allows for objective measurement and a comprehensive understanding of the complex relationships between physical condition, motor skills, and sport-specific skills.

Instruments The research instruments consisted of several tests used to measure each variable in the study.

Physical Conditioning

Physical condition was measured through several fitness components relevant to the characteristics of badminton, including: (1) Leg strength using a leg dynamometer test, (2) Arm strength using a handgrip dynamometer, (3) Endurance using the multistage fitness test, (4) Speed using the 30-meter sprint test, (5) Agility using the Illinois agility test, (6) Power using the vertical jump test, (7) Flexibility using the sit-and-reach test, and (8) Balance using the stork balance test. These instruments demonstrated good validity and reliability, ranging from 0.80 to 0.95 across various sport populations (Tomkinson et al., 2018).

Motor Skills

This variable was measured using the Test of Gross Motor Development-2 (TGMD-2), which consists of two components: locomotor skills (run, hop, gallop, slide, leap, jump) and object control skills (throw, catch, strike, dribble, kick, roll). Scoring was conducted following the procedures outlined by Valentini et al. (2022), with an inter-rater reliability of 0.90. This test has demonstrated strong construct validity and high reliability, with reliability coefficients ranging from 0.85 to 0.96 (Dale A. Ulrich, 2017).

Basic Badminton Skills

Basic badminton skills were measured through several technical skill tests, including: (1) Service test, (2) Lob test, (3) Smash test, and (4) Wall volley test. These tests were used to assess the accuracy and effectiveness of strokes in badminton performance. Previous studies have shown that badminton skill tests possess good validity in measuring players' technical performance and high reliability, with reliability coefficients above 0.85 (Phomsoupha & Laffaye, 2015).

Statistical analysis

Data analysis was conducted using Structural Equation Modeling to examine the structural relationships among physical conditioning, motor skills, and basic badminton skills. The SEM analysis was performed using JASP statistical software. The analysis process consisted of two main stages:

Measurement Model (Confirmatory Factor Analysis / CFA)

This stage aimed to evaluate the construct validity and reliability of the indicators for each latent variable used in the study.

Structural Model Analysis

This stage aimed to test the causal relationships between exogenous and endogenous variables within the research model. Model fit was assessed using several goodness-of-fit indices, including Chi-square, CFI (Comparative Fit Index), TLI (Tucker-Lewis Index), RMSEA (Root Mean Square Error of Approximation), and SRMR (Standardized Root Mean Square Residual). The model was considered to have a good fit if it met the recommended criteria for SEM model adequacy (Hair et al., 2021).

Results

The study used Structural Equation Modeling (SEM) in JASP software to analyze relationships among physical conditioning, motor skills, and basic badminton skills. First, a measurement model was tested using Confirmatory Factor Analysis (CFA) to confirm the validity and reliability of the indicators for the latent constructs. Then, a structural model was tested to identify causal relationships between the variables. The results are summarized below:

Model Fit Evaluation (Goodness of Fit)

The results indicate that the SEM model demonstrates an excellent level of fit. The Comparative Fit Index (CFI) value of 1.000 and the Tucker–Lewis Index (TLI) value of 1.024 indicate a very high level of model fit with the empirical data. In addition, the Root Mean Square Error of Approximation (RMSEA) value of 0.000, with a 90% confidence interval ranging from 0.000 to 0.013, and the Standardized Root Mean Square Residual (SRMR) value of 0.039 indicate a very small estimation error. The Goodness of Fit Index (GFI) value of 1.000 further confirms that the model explains the data exceptionally well. Overall, these fit indices meet the recommended criteria in SEM analysis, indicating that the model is fit and appropriate for further structural analysis.

Table 1. Structural Equation Modeling Results

Model Fit Index	Value	Cut-off Criteria	Interpretation
Chi-square (χ^2)	195.6	$p > 0.05$	Model fit
df	227	—	—
p-value	0.936	> 0.05	Good fit
CFI (Comparative Fit Index)	1	≥ 0.90	Excellent
TLI (Tucker–Lewis Index)	1.024	≥ 0.90	Excellent
RMSEA (Root Mean Square Error of Approximation)	0	≤ 0.08	Excellent
RMSEA 90% CI	0.000 – 0.013	≤ 0.08	Good
SRMR (Standardized Root Mean Square Residual)	0.039	≤ 0.08	Good fit
GFI (Goodness of Fit Index)	1	≥ 0.90	Excellent

Measurement Model

The factor loading results indicate that all indicators significantly contribute to their respective latent constructs. In the basic badminton skills variable, indicator BS2 shows an estimated value of 1.015 with a significance level of $p < 0.001$, indicating a strong relationship with the construct. Other indicators also demonstrate high loading values, suggesting that all indicators used in this study possess good construct validity in representing their respective latent variables.

The R-squared (R^2) values for the indicators reflect the extent to which the latent constructs explain the observed variables. For the physical conditioning variable, R^2 values range from 0.869 to 0.941, indicating that indicators such as strength, endurance, speed, agility, power, flexibility, and balance strongly represent the construct. For motor skills, locomotor and object control indicators show R^2 values between 0.587 and 0.755, reflecting moderate to strong contributions. Meanwhile, the basic badminton skills indicators demonstrate very high R^2 values ranging from 0.812 to 0.972, indicating that service, lob, smash, and wall volley are highly representative of the construct.

Table 2. Measurement Model Results

Latent Variable	Indicator	Loading	p-value	Interpretation
Basic Skills	BS1	1	—	Reference
	BS2	1.015	<0.001	Valid
	BS3	0.939	<0.001	Valid
	BS4	0.909	<0.001	Valid
Motor Skills	LS1	1	—	Reference
	LS2	1.027	<0.001	Valid
	LS3	0.951	<0.001	Valid
	LS4	1.022	<0.001	Valid
	LS5	1.009	<0.001	Valid
	OC1	0.941	<0.001	Valid
	OC2	1.045	<0.001	Valid
	OC3	0.931	<0.001	Valid
	OC4	1.055	<0.001	Valid
	OC5	0.956	<0.001	Valid
	OC6	1.052	<0.001	Valid
Physical Conditioning	PC1	1	—	Reference
	PC2	0.449	<0.001	Valid
	PC3	0.434	<0.001	Valid
	PC4	-0.021	<0.001	Valid
	PC5	-0.055	<0.001	Valid
	PC6	0.691	<0.001	Valid
	PC7	0.521	<0.001	Valid
	PC8	0.436	<0.001	Valid

Structural Model Results

The structural model analysis shows that the exogenous variables moderately explain the endogenous variable. The R^2 value for basic badminton skills is 0.366, indicating that 36.6% of the variance in basic badminton skills is explained by physical conditioning and motor skills, while the remaining variance is influenced by other factors outside the model. This suggests that physical condition and motor skills make a meaningful contribution to the development of basic badminton skills.

Table 3. Coefficient of Determination

Endogenous Variable	R^2	Interpretation
Basic Skills Badminton	0.37	The model explains 36.6% of the variance in badminton basic skills

Overall, the SEM analysis indicates that the conceptual model integrating physical conditioning and motor skills in explaining basic badminton skills demonstrates excellent model fit and is capable of explaining the structural relationships among variables effectively.

Table 4. Structural Model (Path Coefficients)

Dependent Variable	Independent Variable	Coefficient (β)
Basic Skills	Physical Conditioning	0.244

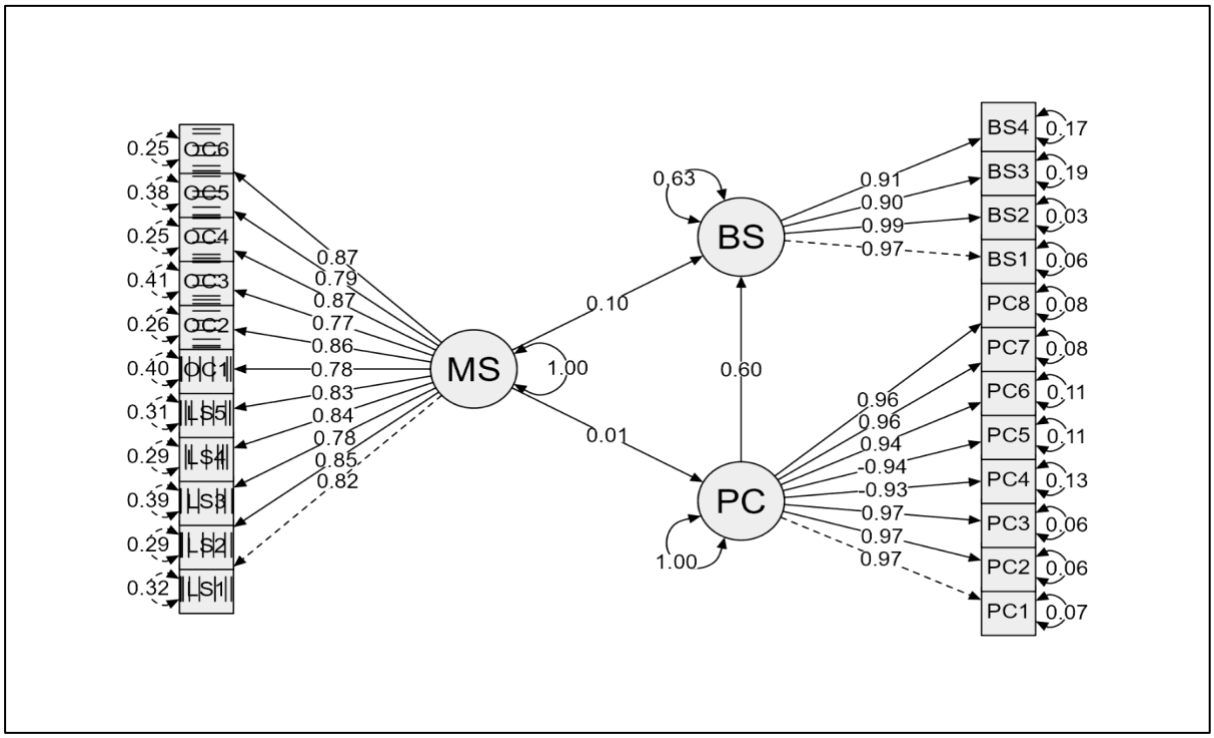

Figure 1. Structural Model Path Diagram

Discussion

The findings of this study indicate that the conceptual model integrating physical conditioning, motor skills, and basic skills in badminton is able to comprehensively explain the relationships among constructs. These results reinforce the view that sport skill performance is not determined by a single factor, but rather is the result of the interaction of multiple physical and motor components operating simultaneously. In game sports such as badminton, technical skills develop through an adaptive process involving the neuromuscular system, movement coordination, and individual physical capacity. Research in sport science suggests that technical skills in racket sports evolve through the integration of physical abilities, motor coordination, and complex movement control (Krizkova et al., 2021; Phomsoupha & Laffaye, 2015).

The findings also reveal that physical conditioning plays a significant role in supporting the mastery of basic badminton skills. Badminton requires players to perform explosive movements such as jumping, rapid changes of direction, and repeated acceleration and deceleration. Good physical condition enables players to maintain body stability and generate optimal stroke power throughout the game. Previous studies have shown that components of physical fitness, including muscular strength, endurance, speed, and agility, are critical factors influencing performance in racket sports, as they support movement efficiency and the ability to reach the shuttlecock effectively (Abián et al., 2014; Krizkova et al., 2021). Individuals with better physical conditioning also tend to maintain technical performance quality during high-intensity gameplay.

In addition to physical conditioning, this study highlights that motor skills serve as a fundamental foundation for mastering sport-specific technical skills. Basic motor skills, such

as locomotor skills and object control, form the basis of movement coordination required in various sports. In badminton, players must integrate rapid footwork with precise racket control to produce effective strokes. Literature on motor development indicates that fundamental motor skills are strongly associated with the development of more complex sport skills (Barnett et al., 2016; Logan et al., 2018). Individuals with better motor coordination tend to learn technical skills more quickly due to more efficient movement control.

Motor skills are also closely related to the function of the neuromuscular system in coordinating different components of body movement. In badminton, players must integrate footwork, body rotation, and hand–eye coordination to produce accurate strokes. This coordination process involves the interaction between the nervous and muscular systems, enabling the body to execute effective and controlled movements. Research in human movement science shows that motor coordination plays a key role in improving movement efficiency and reducing technical errors during sport activities (Lubans et al., 2012; Stodden et al., 2008). Athletes with good movement coordination tend to perform technical skills with greater consistency.

Furthermore, the findings support the concept that sport performance is multidimensional. Technical skills in sports are influenced not only by physical and motor abilities, but also by other factors such as playing experience, training quality, game strategy, and psychological readiness. Literature in sport science emphasizes that athletic performance is the result of the integration of physical, technical, tactical, and psychological components developed through continuous training processes (Folgado et al., 2019; Ghorpade et al., 2024). A research approach that integrates multiple factors within a single analytical model provides a more comprehensive understanding of sport performance determinants.

The practical implications of this study suggest that the development of badminton skills should not rely solely on technical training. The learning and training process should integrate the development of physical conditioning and motor skills as foundational elements for mastering technical skills. Well-designed, integrated training programs enable players to develop technical skills more effectively, as they are supported by adequate physical capacity and movement coordination. Research in sport training demonstrates that programs combining physical training, motor coordination, and technical practice can enhance sport performance more effectively than approaches focusing on a single aspect (Bishop et al., 2018; Granacher & Borde, 2017).

This study contributes to the development of analytical models in sport skill research by integrating physical conditioning and motor skills within a single structural framework to explain basic badminton skills. This approach provides a more comprehensive understanding of the factors influencing sport skill acquisition. The findings also open opportunities for future research to develop broader models by incorporating additional variables such as psychological factors, training experience, and tactical aspects of the game, thereby offering a more holistic perspective on sport performance determinants.

Conclusions

This study demonstrates that the mastery of basic skills in badminton is the result of the interaction between physical conditioning and motor skills, which operate simultaneously in supporting players' technical performance. Good physical condition provides a physiological foundation that enables individuals to perform various explosive movements, rapid changes of direction, and maintain body stability during gameplay. Meanwhile, motor skills play a crucial role in coordinating body movements and object control effectively to produce accurate strokes. The integration of these two factors forms an essential foundation in the development of badminton technical skills. These findings emphasize that sport skill development cannot be separated from the integrated development of physical capacity and motor coordination.

Therefore, training and instructional approaches that combine physical fitness, motor skills, and technical practice represent a more effective strategy for enhancing skill performance in badminton.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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