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Associations of Shoulder Flexibility and Hand Reaction Speed with Table Tennis Smash Performance among Senior High School

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Abstract

Table tennis smash performance requires technical coordination and sensorimotor responses, yet evidence linking simple physical and neuromotor measures to this skill remains limited. This study examined the individual and joint associations of shoulder flexibility and hand reaction speed with table tennis smash performance. A quantitative correlational design involved 15 male members of a school table tennis team, selected through total population sampling. Shoulder flexibility was assessed using a stick-assisted shoulder movement test, with the best of three trials recorded. Hand reaction speed was measured by a ruler drop test, while smash performance was assessed across ten target-directed strokes. Data were analyzed using Pearson correlation and multiple linear regression at a significance level of 0.05. Shoulder flexibility showed a weak, nonsignificant negative correlation with smash performance ($r = -0.251$; $p = 0.367$). A similarly weak, nonsignificant association was found for hand reaction speed ($r = -0.185$; $p = 0.510$). The combined regression model was not significant, $F(2,12) = 0.506$; $p = 0.615$, with $R^2 = 0.078$. These findings suggest that the measured characteristics explained little variation in smash scores within this sample. They do not establish the absence of an association in the wider population. Interpretation is limited by the small sample size, restricted variation in smash scores, and incomplete information on instrument measurement properties. Skill assessment should therefore also consider direct evaluation of stroke technique and task-specific measurement.

Keywords: hand reaction speed; school students; shoulder flexibility; smash performance; table tennis.

INTRODUCTION

Table tennis is an open skill sport that demands the integration of perceptual abilities, movement coordination, decision-making, and stroke control in a relatively short time. Players must adjust body position, swing direction, and bet orientation to changes in speed and ball rotation. Lanzoni et al. (2021) showed that the characteristics of bet position and tilt differ based on the direction of the forehand topspin stroke, while Mao et al. (2023) identified changes in biomechanical characteristics when players face different types of ball spins. Bańkosz et al. (2026) also found a relationship between the distribution of foot pressure and bet speed during the execution of the forehand topspin. These findings indicate that table tennis stroke performance is the result of coordination of various movement components, not just the ability of one part of the body.

One of the attacking skills in table tennis is the *smash* shot, which requires accelerated arm movement, precise contact timing, and the ability to direct the ball toward the target area. Successful shots require coordination between body position, bat movement, and ball direction control. Lyu et al. (2025) showed that the parameters of shoulder, elbow, wrist movement, and body rotation correlate with ball speed in forehand shots. Haryanto and Becerra-Patiño (2023) also found a positive relationship between eye-hand coordination and backhand drive accuracy. Although the study showed the relevance of motor function to stroke quality, the characteristics of forehand and backhand drive differ from smash tasks, so the results cannot be generalized directly.

The complexity of table tennis shots can also be understood through the contribution of lower limb and torso movements. He et al. (2021) found differences in leg kinematic characteristics based on players' skill levels, while He et al. (2022) outlined differences in muscle force demands in step pattern variations during forehand topspin strokes. He et al.'s (2023) study showed differences in waist and hip movement characteristics based on stroke direction. Zhu et al. (2023) also identified differences in lower limb movements in players with different skill levels, while Winiarski et al. (2021) highlighted the role of arms not holding the bar during forehand execution. This evidence shows that punching skills involve coordination between body segments and movement adjustments that are not fully reflected through a single physical ability indicator.

Shoulder joint flexibility is one of the physical components that theoretically can support arm movement space in hitting execution. Shoulder mobility allows players to adjust arm position and swing trajectory, but these abilities need to be distinguished from proprioception, strength, stability, and movement coordination. Chen et al. (2025) reported the association between shoulder proprioception and forehand stroke accuracy in elite table tennis athletes, especially in the context of fatigue. In contrast, Ceylan et al. (2026) found no significant relationship after multiple corrections between shoulder rotational range of motion and rotational strength with smash speed in badminton players. The study by Kumar and Das (2024) shows the importance of the interaction of kinematic, kinetic, and neuromuscular parameters in racket *sports* smash performance. These differences in findings and constructs indicate that shoulder flexibility cannot be directly assumed to be a strong indicator of a strong relationship with table tennis smash ability without empirical testing.

Besides shoulder flexibility, hand reaction speed is a neuromotor ability relevant to the demands of table tennis. Players must recognize stimuli, determine responses, and initiate movements within a limited time. However, simple reaction speed needs to be distinguished from choice reactions, ball anticipation, and the ability to integrate responses with strokes. Zhang et al. (2026) showed that reactive agility training produces specific changes in choice reactions and step-stroke integration tasks in young table tennis players. A systematic review by Lu et al. (2026) also emphasized the importance of distinguishing reaction time, technique performance, and decision-making as distinct sports outcomes. In badminton, Hülsdünker et al. (2021) found that sensory stimulus characteristics affect visuomotor response speed. These findings show that the results of measuring reactions to simple stimuli do not necessarily reflect response ability in complex game situations.

In school table tennis coaching, assessment of physical ability and technical skills is necessary to obtain information about participant characteristics. One issue that needs to be answered is whether shoulder flexibility and hand reaction speed are related to students' success in hitting the target area. The use of simple instruments allows measurements to be made in training environments with limited facilities, but the results must be interpreted according to the constructed being measured. The similarity of general functions as motor components does not guarantee that shoulder flexibility and hand reaction speed have the same relationship with smash skills. Therefore, the assessment of these two indicators needs to be supported by empirical testing, not just arguments about the importance of physical condition in racket sports.

Previous research has shown that the relationship between sensorimotor ability and technical skills can differ according to measurement characteristics. Cao et al. (2026) found that ankle proprioception in lateral movements provides additional explanatory ability for table tennis stroke performance in adolescents in regression models. Haryanto and Becerra-Patiño (2023) reported the

relationship between eye-hand coordination and backhand drive accuracy, while Zhang et al. (2026) showed that changes in reaction performance after training depend on the type of task used. All three studies support the importance of sensorimotor function but use different constructs, instruments, and skill indicators such as shoulder flexibility, simple hand reactions and smash ability. These differences are the reason for the need for a more specific relationship analysis of the research variables.

Not all movement indicators have a significant relationship with sports skill outcomes. Kędziorek et al. (2025), for example, did not find a significant association after multiple comparison corrections between the mass center movement parameter and certain performance indicators in para-table tennis players. The results of Ceylan et al. (2026) also showed that the relationship between shoulder physical characteristics and stroke speed is not always significant in the context of other racket sports. Although the characteristics of participants and instruments in both studies differ from this study, the findings highlight the importance of testing relationships between variables without if all physical components correlate with technique performance. The absence of statistical relationships should also be understood as empirical results that can provide information about the limitations of an indicator in a particular measurement context.

The measurement aspect is another consideration in evaluating hitting ability. The review by Kong and Ma (2024) on the para-table tennis skill instrument emphasizes the importance of standardization of procedures, scoring provisions, as well as evidence of validity and reliability. In racket sports, Yu et al. (2026) showed that the development of physical ability through core strength training can be related to various performance indicators, but the intervention findings did not directly explain the relationship between shoulder flexibility and hand reaction with smash scores. Because smash ability is a skill involving accuracy, coordination, and movement control, testing the relationship with simple physical-neuromotor indicators must consider differences in task characteristics and the sensitivity of assessment instruments.

Based on this synthesis, the research gap lies in the inadequate evidence in the reviewed literature regarding the strength of the relationship between shoulder joint flexibility and simple hand reaction speed with table tennis smash hitting ability when both analyzed individually and simultaneously in student groups. Previous research has identified the relationship between shoulder proprioception, hand-eye coordination, and choice reactions with specific stroke skill indicators (Chen et al., 2025; Haryanto & Becerra-Patiño, 2023; Zhang et al., 2026). However, these constructs are not identical to the indicators used in this study. The novelty of this research lies in empirical testing of two simple physical-neuromotor characteristics within a correlational model to clarify the magnitude of associations and the proportion of variations in smash ability that can be explained within the studied student group.

This study aims to analyze the relationship between shoulder joint flexibility and hand reaction speed with table tennis smash hitting ability, both individually and simultaneously. The research hypothesis states that there is a relationship between shoulder flexibility and smash ability, a relationship between hand reaction speed and smash ability, as well as the relationship between the two predictor variables together with smash ability. The study used a correlational quantitative design without experimental intervention. Thus, the research results are aimed at providing empirical evidence regarding the strength and direction of the relationship between variables, without establishing cause-and-effect relationships or the effectiveness of specific training methods.

METHODE

Research Design

This study uses a quantitative approach with a correlational design to analyze the relationship between shoulder joint flexibility and hand reaction speed with table tennis smash hitting ability. A correlational design was chosen to estimate the strength and direction of the intervariable relationship based on measurements in the same participant group, without providing experimental treatment. A similar approach was used by Haryanto and Becerra-Patiño (2023) to analyze the relationship between eye-hand coordination and table tennis stroke skills, while Cao et al. (2026) used regression analysis to evaluate the relationship between sensorimotor ability and stroke performance. Correlational research on coordination components and sports skills was also used by Nurodin et al. (2024). This study involves two predictor variables and one outcome variable with interpretation limited to statistical relationships not cause and effect.

Research Participants

The research participants consisted of 15 male students who were part of the table tennis team at MA As-Syafi'iah Pemenang in North Lombok Regency. The sampling technique used was population study involving all members of the accessible population who met the research criteria. Participant criteria included male students who actively participated in school table tennis activities, willing to participate in a series of measurements, and not currently experiencing shoulder, arm, or hand injuries that could interfere with the test implementation. Participant characteristics are important information in table tennis performance research because motor development, playing experience, and skill levels are related to the context of interpreting measurement results. Cao et al. (2026) involved adolescent table tennis athletes in the correlational study, while Zhang et al. (2026) reported the characteristics and criteria of young player participants in detail.

Research Variables and Instruments

The study involved three main variables. Shoulder joint flexibility (X1) is defined as shoulder joint mobility assessed through the results of a movement test using a stick. Hand reaction speed (X2) is the hand's response to visual stimulus measured using a ruler drop test. Smash strike ability (Y) is the result of attack strike skills assessed based on the accumulated score of successfully directing the ball to the target area. The three variables represent different constructs and must be interpreted according to the characteristics of each instrument. Chen et al. (2025) examined shoulder proprioception in relation to stroke accuracy, while Zhang et al. (2026) measured choice reactions and stroke-stroke performance. Lyu et al. (2025) showed that stroke skill evaluation can also involve more complex kinematic parameters. The literature supports the importance of distinguishing physical, neuromotor, and skill outcome indicators.

Shoulder flexibility was measured using a shoulder joint motion test assisted by a stick and measuring movement distance. Each participant was given three measurement opportunities, and the best result was used as the research score. This instrument is used to describe shoulder joint mobility and does not directly measure shoulder strength, stability, or coordination during smash. Ceylan et al. (2026) distinguish between shoulder rotational range measurements and rotational strength measurements in racket sports stroke performance analysis. Wheare et al. (2021) also emphasize the importance of validity and reliability checks in upper limb kinematics measurements. These two sources are used as a basis for measuring measurement quality, not as evidence of the validity of the stick test used in this study.

The speed of hand reaction was measured using the ruler drop test. Participants were asked to catch the ruler released by the tester, then the catch result was recorded as the measurement score. This test represents a response to simple visual stimuli, which differs from the choice reaction and anticipation of the opponent's movement in a match. Zhang et al. (2026) used the measurement of choice reactions on young table tennis players, while Hülsdünker et al. (2021) showed that sensory stimulus characteristics affect visuomotor response speed in racket sports. Therefore, the result of the ruler drops test are interpreted according to their construct and measurement units, without equating them with decision-making ability in matches.

Smash hitting ability is measured through ten shots to the target area on the tennis table. The final score is obtained from the accumulated score of shots successfully directed to the target area according to the testing criteria. This instrument is used to describe the success of smash execution on standardized assessment tasks, not the overall attacking performance in the match. Haryanto and Becerra-Patiño (2023) use accuracy-based stroke skill tests, while Kong and Ma (2024) emphasize the importance of procedure standardization, scoring criteria, as well as evidence of validity and reliability in table tennis skill assessment.

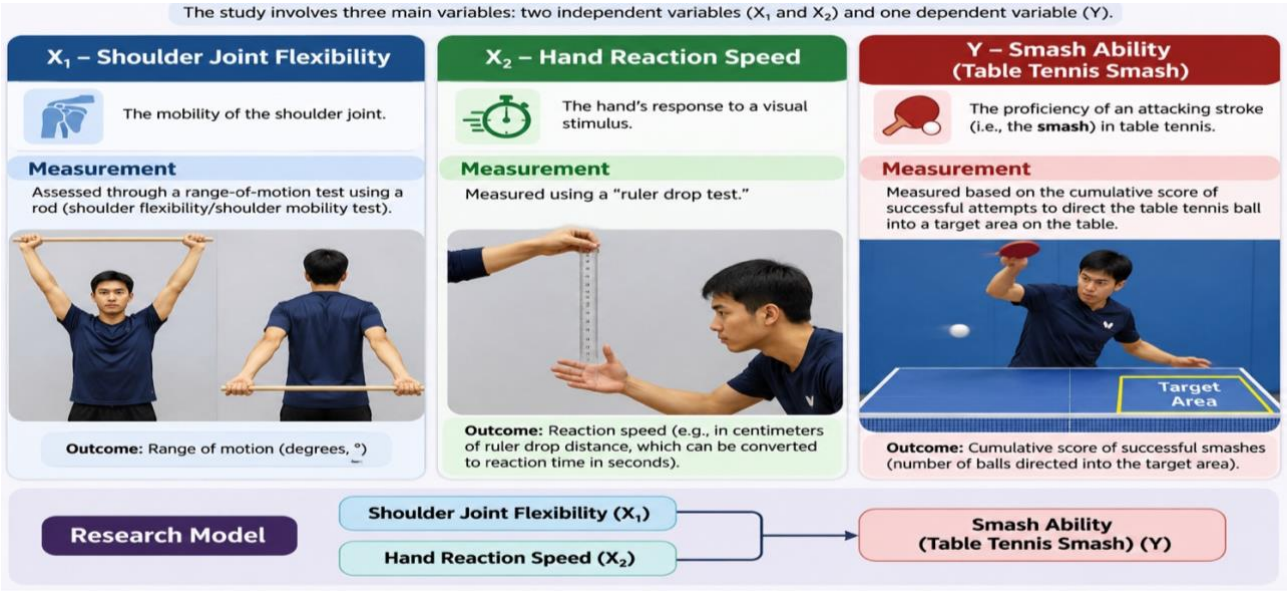


Figure 1. Research Variable

Data Collection Procedure

Data collection was carried out through the preparation stage, measurement implementation, and result recording. The preparation stage included determining participants, preparing equipment, explaining the test procedures, and setting up the testing location. Measurements were conducted sequentially, starting with a shoulder joint flexibility test, followed by a hand reaction speed test, and ending with a smash shot ability test. The results of each test were recorded on the measurement sheet and then analyzed statistically. Consistency in task execution and assessment provisions are important aspects in measuring sports skills. Lanzoni et al. (2021) used table tennis stroke tasks with standardized feeding arrangements, while Kong and Ma (2024) emphasized the need for replicable scoring procedures and systems. Both studies are used as the basis for the importance of standardization, without assuming that the same tools or procedures are used in this study.

Data Analysis Techniques

Data were analyzed using descriptive and inferential statistics. Descriptive statistics included the number of participants, mean, and standard deviation for each variable. Pearson correlation

analysis was used to estimate the direction and strength of the linear relationship between X1 and Y, X2 and Y, as well as X1 and X2. A similar correlational approach was used in table tennis skills research by Haryanto and Becerra-Patiño (2023). Multiple linear regression was used to analyze the relationship between shoulder flexibility and hand reaction speed simultaneously with smash ability. Model evaluation included regression coefficients, F-test significance, coefficient of determination (R^2), adjusted R^2, as well as multicollinearity examination through tolerance values and variance inflation factor (VIF). Cao et al. (2026) used regression analysis to evaluate the relationship between sensorimotor characteristics and table tennis stroke performance. The significance level was set at $\alpha = 0.05$. The 95% correlation confidence interval was estimated using the Fisher z-transform of the reported coefficients. Inferential interpretation needs to consider linearity, observation independence, outliers, regression residual normality, homoscedasticity, and influential observations. The analysis results are interpreted as statistical relationships not as evidence of causal influence.

RESULTS

Descriptive analysis was conducted on measurements of shoulder joint flexibility, hand reaction speed and table tennis smash ability on 15 study participants. Descriptive statistics were used to describe the tendency of scores and score distributions in each variable before conducting relationship analysis. Based on Table 1, smash hitting ability has an average score of 29.00 with a standard deviation of 0.85. The relatively narrow distribution of smash scores indicates that the difference in measurement results among participants in this group is limited. Shoulder flexibility and hand reaction speed showed average values of 56,278.40 and 143.87, respectively. A direct comparison of the values between variables was not conducted because all three used different measurement systems.

Table 1. Descriptive Statistics of Research Variables

	Mean	Std. Deviation	N
Smash	29.0000	.84515	15
Shoulder Flexibility	56278.4000	1392.22693	15
Hand Reaction	143.8667	3.20416	15

Pearson correlation analysis was used to test the linear relationships between variables. The test results showed that shoulder joint flexibility and hand reaction speed did not have a statistically significant relationship with *smash* strike ability in the study participant group.

Table 2. Pearson Correlation Between Variables

		Shoulder Flexibility	Hand Reaction	Smash
Shoulder Flexibility	Pearson Correlation	1	.268	-.251
	Sig. (2-tailed)		.333	.367
	N	15	15	15
Hand Reaction	Pearson Correlation	.268	1	-.185
	Sig. (2-tailed)	.333		.510
	N	15	15	15
Smash	Pearson Correlation	-.251	-.185	1
	Sig. (2-tailed)	.367	.510	
	N	15	15	15

Shoulder flexibility has a weak negative relationship with smash ability ($r = -0.251$; $p = 0.367$). Hand reaction speed also shows a weak negative relationship with smash ability ($r = -0.185$;

p = 0.510). Both relationships are not statistically significant, and the confidence intervals each include zero values. The relationship between shoulder flexibility and hand reaction speed shows a weak positive coefficient (r = 0.268; p = 0.333), but not significant. Thus, the analysis results do not provide sufficient evidence regarding the linear relationship between the two predictors and the smash strike ability in the sample studied.

Substantively, these results indicate that increased shoulder flexibility and hand reaction are not necessarily accompanied by improvements in smash hitting ability. In the context of racket sports, stroke performance is not determined by just one physical component but is the result of interactions between movement coordination, stroke technique, racket control, ball contact time, body stability, training experience, and perceptual-motor ability. This aligns with the biomechanics study of table tennis, which confirms that stroke quality is influenced by a combination of skill levels, game maneuvers, body segment coordination, and specific movement characteristics of the sport (Wong et al., 2020; Chen & Zhao, 2025). In other racket sports, smash quality is also influenced by torso coordination, upper extremities, strength, and complex movement patterns, not just by flexibility or separate hand reactions (Barnamehei et al., 2022; Yu et al., 2025; Ramasamy et al., 2024).

Multiple linear regression analysis was conducted to evaluate the relationship between shoulder flexibility and hand reaction speed simultaneously with smash strike ability. The analysis results showed that the regression model was not statistically significant.

Table 3. Multiple regression ANOVA results

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.777	2	.389	.506	.615[b]
	Residual	9.223	12	.769		
	Total	10.000	14			

The coefficient of determination of $R^2 = 0.078$ indicates that the combination of shoulder flexibility and hand reaction speed explains about 7.77% of the variation in smash ability scores in the research sample. The adjusted R^2 value of −0.076 indicates that the model's explanatory ability is very limited after considering the number of predictors and sample size. Simultaneous testing results show that the regression model is not significant, F (2.12) = 0.506; p = 0.615. Thus, the two predictors together have not shown a significant linear relationship with smash ability.

The coefficient test results showed that shoulder flexibility was not a significant predictor of smash ability (β = -0.217; t = -0.753; p = 0.466). Hand reaction also did not become a significant predictor of smash ability (β = -0.126; t = -0.439; p = 0.668). These results indicate that both variables do not yet have a significant partial relationship with smash ability after being calculated simultaneously in the model.

Table 4. Regression Coefficients

		Unstandardized Coefficients		Standardized Coefficients			Correlations			Collinearity Statistics	
	Model	B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	41.206	12.584		3.275	.007					
	Shoulder Flexibility	.000	.000	-.217	-.753	.466	-.251	-.213	-.209	.928	1.078
	Hand Reaction	-.033	.076	-.126	-.439	.668	-.185	-.126	-.122	.928	1.078

Shoulder flexibility had a negative and insignificant standardized regression coefficient (β = −0.217; p = 0.466). Hand reaction speed also had a negative and insignificant standardized regression

coefficient ($\beta = -0.126$; $p = 0.668$). Both predictors did not show a significant partial relationship with smash strike ability after being combined into the model. A tolerance value of 0.928 and a VIF of 1.078 for both predictors did not indicate a serious multicollinearity. Overall, the Pearson correlation and multiple linear regression results indicate that shoulder joint flexibility and hand reaction speed have not yet a statistically significant relationship with table tennis smash hitting ability in study participants, either individually or simultaneously. These findings illustrate the limited evidence linking the two predictor variables to smash scores in the studied sample and serve as a basis for further discussion regarding measurement characteristics, sample limitations, and the complexity of table tennis hitting skills.

DISCUSSION

The main findings of this study show that shoulder joint flexibility and hand reaction speed have not shown a significant relationship with table tennis smash hitting ability, either individually or simultaneously. These findings indicate that the physical-neuromotor characteristics measured separately do not sufficiently provide an overview of differences in smash skills among the studied student groups. Conceptually, this condition can be understood because the success of smash shots is the result of integrating several movement components, including body position regulation, coordination between joints, ball contact accuracy, and stroke direction control. Therefore, the results of the study cannot be interpreted as saying that shoulder flexibility and hand reaction speed are unimportant, but rather that the relationship between these two abilities and smash skills has not received adequate empirical support in the context of this study's measurements. These findings serve as the basis for further examining the differences in physical-neuromotor ability characteristics, the demands of punching skills, and the suitability of measurement instruments.

Biomechanically, table tennis shots are the result of coordination of several body segments working in an integrated sequence of movements. Lyu et al. (2025) showed that forehand ball speed is related to parameters of shoulder, elbow, wrist, and body rotation movement. Mao et al. (2023) identified changes in stroke characteristics when players face different ball spins, while He et al. (2023) showed differences in waist and hip kinematics based on stroke direction. Lanzoni et al. (2021) also explained the characteristics of bet position during forehand topspin, while Winiarski et al. (2021) examined the role of arms not holding the stick. In addition, Chow and Lee (2024) showed the presence of plantar load distribution characteristics and postural balance in table tennis players with different skill levels. Sugiharto et al. (2025) examined the relationship between bet material characteristics and aspects of stroke speed and control. All this evidence supports the understanding that stroke results are influenced by task characteristics, body coordination, and equipment used, although these factors were not directly tested in this study.

The absence of a significant relationship between shoulder flexibility and smash ability needs to be understood through the difference between joint mobility and movement control when hitting. Flexibility describes the ability of the joint to move within a certain range of motion, whereas stroke success requires position regulation, stability, segment acceleration, and contact accuracy. Chen et al. (2025) found a relationship between shoulder proprioception and forehand accuracy in elite table tennis athletes, especially under fatigue conditions. However, proprioception is a sensorimotor ability that differs from flexibility. In badminton, Wang and Zhou (2024) reported changes in shoulder flexibility and smash speed characteristics after training programs, while Ceylan et al. (2026) did not find a significant relationship between shoulder rotational range of motion or rotational strength with

smash sspeed aftermultiple ratio correction. These differences in results indicate the importance of considering measurement constructs, research design, and skill characteristics before concluding the relationship between shoulder flexibility and stroke results.

The biomechanical study of hitting movements provides additional explanation regarding the limitations of measuring flexibility as an indicator of technique performance. Barnamehei et al. (2021) showed that modeling shoulder joint complexes in overhead smash movements needs to consider relationships between shoulder components, not just glenohumeral joint movements. Rusdiana (2021) identified differences in the kinematic characteristics of the shoulder, elbow, and wrist between forehand and backhand smash shots in badminton. Dong et al. (2024) found changes in muscle activation and angle speed of the upper extremities when the target smash distances differed. Furthermore, Tajik et al. (2025) identified patterns of shoulder muscle synergy during overhead smash, while Guo and Lin (2026) outlined the sequence of body segment contributions in badminton smash movements. This evidence illustrates the importance of movement organization and neuromuscular coordination but should not be treated as direct evidence of the relationship between shoulder flexibility and table tennis smash ability.

A weak and insignificant negative relationship between hand reaction speed and smash ability also needs to be interpreted based on the characteristics of the measurement task. The rulers drop test measures hand response to simple visual stimuli, while performing a smash demand the ability to predict ball trajectory, determine body position, and regulate contact timing. Zhang et al. (2026) found that the additional benefit of reactive agility training in young table tennis players is specific to choice reactions and step-stroke integration tasks. Lu et al. (2026) also distinguish reaction time, technique performance, and decision-making as domains of sports ability that have different characteristics. Thus, the meaninglessness of the relationship between hand reaction scores and smash ability may be related to differences in the demands of the two tasks, but this explanation is still possible and has not been directly tested.

Differences between simple responses and stroke skills are also seen in studies of perceptual ability and bet control in racket sports. Tan and Teoh (2024) examined the relationship between quiet eye characteristics, visual attention, and biomechanical parameters with prediction of badminton stroke accuracy. Wang et al. (2026) showed that mixed reality-assisted learning can be related to changes in visual attention and stroke results in beginner badminton players. Meanwhile, Pan et al. (2024) identified the distribution characteristics of finger grip force in several types of badminton shots, while Rigozzi et al. (2023) reported differences in forearm muscle activity during forehand shots between experienced and recreational tennis players. These studies show that assessment of hitting skills can involve visual attention, grip regulation, and muscle coordination. However, these components have not been measured in this study and therefore cannot be stated as an empirical explanation for the insignificant correlation results.

These results need to be carefully compared with table tennis studies using different sensorimotor instruments. Cao et al. (2026) found that ankle proprioception during lateral movement provides additional explanatory ability to affect stroke performance in adolescent table tennis athletes. Haryanto and Becerra-Patiño (2023) also reported a positive relationship between eye-hand coordination and backhand drive accuracy. In contrast, Kędziorek et al. (2025) found no significant relationship after multiple comparison corrections between several indicators of mass center movement and accuracy and technique assessment in para-table tennis players. Huang et al. (2024) also showed that some kinematic characteristics of backhand squash shots differ according to skill

level, while other parameters do not show significant differences. This comparison shows that the strength of the relationship between physical or sensorimotor characteristics and skill outcomes depends on the construct, participant characteristics, and the type of task analyzed. Therefore, the results of this study should not be seen as contradictory to all previous findings.

The measurement factor of smash ability is another important consideration. Narrow variation can reduce the sensitivity of correlation analysis to distinguish relationships between abilities, although it is not sufficient to ensure the existence of a ceiling effect without information on maximum scores and individual distributions. Ramasamy et al. (2025) showed that the jump smash performance of elite badminton athletes can vary between experiments due to changes in movement characteristics and contact time. Krishnaram et al. (2024) developed a body skeletal point analysis approach to evaluate movement characteristics related to badminton smash accuracy. Meanwhile, Kong and Ma (2024) emphasize that table tennis skill assessment requires standardized procedures and scoring as well as evidence of adequate validity and reliability.

Theoretically, the research results show the importance of distinguishing basic ability indicators from specific sports skill performance. The speed at which a response begins is not always equal to the accuracy of execute a shot, just as shoulder mobility is not the same as the ability to coordinate punch movements. A review by Ding et al. (2024) shows that mental fatigue can affect stroke performance and psychomotor responses in some racket sports, including table tennis. These findings show that cognitive conditions and attention are also relevant in the discussion of performance, although mental fatigue was not measured in this study. The conceptual contribution of this research lies in strengthening the need for alignment between the measured physical-neuromotor constructs and the stroke skills used as outcome indicators. These contributions are empirical and limited, not proof of new neuromotor mechanisms.

In the context of school table tennis coaching, research findings provide reasons not to use shoulder flexibility and simple hand reaction tests as the sole basis for assessing smash ability. Physical education teachers and coaches can consider skill evaluations covering starting position, step patterns, swing preparation, contact time, bar orientation, and ball placement accuracy. Zhang et al. (2026) demonstrated the importance of alignment between reaction training and punch-movement tasks in young table tennis players. In badminton, Chaeroni and Surur (2023) examined the use of training media and eye-hand coordination in learning playing skills. Both studies provide a basis for consideration for developing more skill-specific training. However, these recommendations are practical implications based on literature and not the effectiveness of training programs that have been proven through this correlational study.

The implementation of training can be directed gradually, starting from mastering the mechanics of ballless shots, followed by target training using consistent passes, then developing into variations in direction, speed, and ball placement. Multiball training can be considered to increase opportunities to hit under controlled conditions before students face more dynamic game situations. Edel et al. (2023) showed that changes in interval duration in badminton's multifeeding training are related to differences in training load, so adjusting training dosage is an aspect that needs attention. Research by Wang et al. (2026) also provides evidence regarding the role of visual learning support in acquiring beginner players' racket skills. In its application to table tennis, the form of training needs to be adjusted to the participants' age, experience, and ability and its effectiveness tested through separate intervention studies.

This study has several limitations that need to be considered. First, the small and limited sample size among male students reduces estimation accuracy and limits the generalization of results. Second, the relatively narrow variation in smash scores potentially limits the ability to test relationships between variables. Third, information regarding units, scoring directions, and standardization of shoulder flexibility measurements as well as hand reaction speed has not been fully reported. Fourth, information on the validity and reliability of smash instruments, including ball delivery consistency and scoring criteria, is still limited. Fifth, results of linearity assumption examination, residual characteristics and influential observations are not yet available in the reviewed report.

Further research needs to involve participants in larger numbers and a wider variety of skill levels. Characteristics of age, class, playing experience, hand dominance, and training frequency need to be noted so that differences among participants can be better analyzed. The shoulder flexibility instrument needs to have clear unit definitions and procedures, while the results of the ruler drop test must be ensured whether in terms of distance or reaction time. The smash ability test also needs to be equipped with scoring rubrics, uniform passing procedures, and reliability checks. Additionally, measurements of eye-hand coordination, technique quality, contact time, and ball anticipation ability can be considered as additional variables. A longitudinal or experimental design is needed if the next research objective is to test whether a particular training program causes an increase in smash ability. Overall, this study provides preliminary evidence that shoulder joint flexibility and hand reaction speed, as measured using research instruments, have not shown a significant linear relationship with table tennis smash ability in the studied student group.

CONCLUSION

This study shows that shoulder joint flexibility and hand reaction speed have not provided adequate evidence of a relationship with table tennis smash hitting ability in the studied student group. These findings indicate that both physical-neuromotor indicators, as measured in this study, are not sufficient to explain differences in smash skills. The scientific contribution of the study lies in the importance of considering the alignment between the measured physical-neuromotor ability characteristics and the demands of the evaluated hitting skills. Practically, smash skill assessment should not only rely on shoulder flexibility and hand reaction but also include direct measurement of stroke techniques. However, limitations in the number of participants, score variations, and instrument quality information require the research results to be interpreted carefully. Future research needs to involve a more diverse range of participants, standardized instruments, as well as measurements of coordinating components and techniques to clarify the relationship between various skill characteristics and table tennis smash skills.

RECOMMENDATION

Physical education teachers and table tennis coaches are advised to implement comprehensive smash skill evaluations, without relying solely on shoulder joint flexibility and hand reaction speed. Assessment should consider mastery of stroke techniques, hand-eye coordination, body position, ball contact accuracy, stroke angle control and stroke accuracy. Training programs should be developed gradually**,** through shadow swing exercises*,* controlled pass stroke training, targeting accuracy training, multiballs and game simulations. Flexibility and hand reaction exercises can still be integrated as supporting components. Schools also need to provide adequate training facilities and

use standardized skill assessment rubrics. Future research is recommended to involve a larger and more diverse sample based on age, skill level, playing experience, and training frequency. The use of instruments needs to be strengthened through clarity of measurement units, testing procedures, scoring systems, as well as validity and reliability testing. Future research may also involve variables such as eye-hand coordination, muscle strength, technique quality and ball anticipation ability. Statistical analysis needs to be complemented by assumption checks and evaluation of estimation uncertainties. To test the effectiveness of training programs in improving smash skills, it is recommended to use an experimental design with a comparison group.

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