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Olahraga, dan Kesehatan**
Indonesian Journal of Physical Education, Sports and Health
e-ISSN 2797-9962
Journal Homepage: <http://journal.unugiri.ac.id/index.php/citius>



The relationship of arm muscle strength and hand-eye coordination with underhand serve ability in elementary school students

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ABSTRACT

The underhand serve is an important basic technique in elementary-school volleyball learning, yet many students still struggle to perform it effectively. Arm muscle strength and hand-eye coordination are often regarded as determinants of serving success, but empirical evidence for elementary-school students remains mixed. This study aimed to determine the relationship of arm muscle strength and hand-eye coordination with the underhand serve ability of elementary-school students. A quantitative correlational design was used. The population comprised all fifth- and sixth-grade students of SD Negeri 13 Tanjungraja (57 students), and 36 students were selected through purposive sampling. The instruments were a 30-second push-up test (arm muscle strength), a tennis-ball throw-and-catch test (hand-eye coordination), and a 10-attempt underhand serve test (serving ability). Data were analysed with descriptive statistics, the Kolmogorov-Smirnov normality test, the Spearman correlation, and, as an exploratory step, multiple linear regression. Neither arm muscle strength nor hand-eye coordination showed a significant relationship with underhand serve ability, either partially or simultaneously; together the two variables explained only about 6.5% of the variance ($R^2 = 0.065$; $F(2,33) = 1.14$; $p = 0.330$). Underhand serve ability therefore appears to be shaped more by pedagogical factors and technical mastery than by these physical components alone. Volleyball instruction in elementary schools is recommended to emphasise active, contextual, and movement-oriented learning experiences centred on mastering basic technique.

Keywords: physical education; underhand serve; arm muscle strength; hand-eye coordination; elementary school

OPEN ACCESS



Received: 02 February 2026; Accepted 28 July 2026; Published 03 August 2026

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How to Cite: Ferryuda, M. I., Hardiyono, B., Sukmawati, N., Muslimin, & Endrawan, I. B. (2026). The relationship of arm muscle strength and hand-eye coordination with underhand serve ability in elementary school students. *Citius: Jurnal Pendidikan Jasmani, Olahraga, dan Kesehatan*, 6(2), 29–36. <https://doi.org/10.32665/citius.v6i2.6317>

Authors' Contribution*: a – Study Design; b – Data Collection; c – Statistical Analysis; d – Manuscript Preparation; e – Funds Collection.

INTRODUCTION

Physical education plays a strategic role in developing the physical, motor, cognitive, and social aspects of students, especially at the elementary-school level (Utamayasa, 2021). Through sport activities, students not only build physical fitness but also develop basic motor skills, movement coordination, and attitudes of sportsmanship and cooperation (Bartolo et al., 2024). Volleyball is one of the sports commonly taught in elementary-school physical education and is regarded as an effective means of developing the manipulative and coordinative motor skills appropriate to a child's developmental stage (Vialli et al., 2021; Yanti et al., 2021).

The serve is the basic technique that starts the game and also functions as the first form of attack (Maifa & Barantai, 2021). For elementary-school children, the underhand serve is considered the most appropriate technique because it is relatively easy to learn, does not require high explosive strength, and allows students to move with better control (Marsuna, 2023). In practice, however, many elementary-school students still struggle to perform the underhand serve effectively, both in hitting power and in directional accuracy.

This difficulty suggests that the success of an underhand serve is determined not only by technical mastery but also by physical condition and coordination (Nurjana et al., 2022; Rusli, 2025). Two components often highlighted are arm muscle strength and hand-eye coordination. Arm muscle strength is needed to generate enough thrust to send the ball over the net and into the opponent's court, while hand-eye coordination helps ensure precise contact between the hand and the ball.

Several previous studies have examined the factors that influence serving skills in volleyball. A number of them report that arm muscle strength contributes to serving success, especially in adolescents or trained students, because it is directly related to the ability to generate hitting force (Setiawan & Mukarohim, 2024; Marwan et al., 2023). Other studies confirm that hand-eye coordination is an important component of manipulative motor skills that require precision and synchronisation between vision and hand movement (Ertanto et al., 2021; Abid et al., 2025).

Nevertheless, the evidence is not entirely consistent, particularly for the elementary-school age group, whose members are still in the basic motor-development stage. Differences in subject characteristics, measurement instruments, and analytical approaches have produced mixed findings (Fajar et al., 2023; Firdaus & Fahrizqi, 2023). In elementary-aged children, muscle strength is not yet fully developed, so its role in technical skill is often mediated by movement technique and overall body coordination, and general coordination does not necessarily transfer directly to sport-specific skills when technical understanding is limited.

This study is distinctive in several respects. It was conducted specifically on elementary-school students, whose motor-development characteristics differ from those of adolescents or athletes; it used a correlational approach within the context of physical-education learning rather than sport achievement; and its instruments were adapted to the abilities of elementary-school students. The urgency of the study lies in identifying the factors that truly contribute to students' underhand serve success, so that it can inform the improvement of volleyball instruction in elementary schools. Accordingly, this study aims to examine, both partially and simultaneously, the relationship of arm muscle strength and hand-eye coordination with the underhand serve ability of elementary-school students, so as to clarify the position of these two variables in physical-education learning.

METHOD

This study used a quantitative approach with a correlational design, which aims to determine the relationship between two or more variables without any treatment or manipulation (Ansar et al., 2024; Gani & Purbangkara, 2023). The population comprised all fifth- and sixth-grade students of SD

Negeri 13 Tanjungraja, totalling 57 students. A purposive sample of 36 students, about 63% of the population, was selected on the basis of being actively enrolled in grades V or VI, present on the testing days, medically fit to perform the physical tests, and having parental consent; students who were absent or physically unable to complete the tests were excluded. Because of the modest sample size, the results should be read as an initial profile, and the study may be underpowered to detect small correlations.

The instruments comprised three tests whose procedures followed those used in prior physical-education research on volleyball serving and coordination, supporting their content validity and reliability (Ertanto et al., 2021; Destriana et al., 2024; Timba & Ritan, 2021). Arm muscle strength was measured with a 30-second push-up test, scored as the number of correct push-ups. Hand-eye coordination was measured with a 30-second tennis-ball throw-and-catch test against a wall, scored as the number of successful catches. Underhand serve ability was measured with a 10-attempt underhand serve test, scored as the number of serves landing in the target area.

The procedure began with a warm-up to prevent injury, after which students completed the arm-strength and hand-eye coordination tests. Underhand serve ability was then measured on the school volleyball court using the same procedure for all participants. All results were recorded by the researcher and an assistant and were double-checked to ensure completeness and accuracy.

Data were analysed using statistical software, beginning with descriptive statistics and a Kolmogorov–Smirnov normality test as a prerequisite. Because two of the three variables were not normally distributed, the Spearman rank correlation was used as the primary analysis. Multiple linear regression was then applied as an exploratory, supplementary step to estimate the combined contribution of the two predictors; because the normality assumption was only partly met, its results are interpreted with caution alongside the non-parametric findings. The significance level was set at $\alpha = 0.05$.

RESULTS

The results are presented from measurements of arm muscle strength, hand-eye coordination, and underhand serve ability. The analysis included descriptive statistics, a normality test, and correlation and regression tests between variables.

Table 1. Descriptive statistics of the research variables

Variable	N	Mean	SD	Min	Max
Arm muscle strength (push-ups)	36	19.94	4.13	9	27
Hand-eye coordination	36	12.94	2.54	5	17
Underhand serve ability	36	6.25	1.27	4	9

On average, arm muscle strength was 19.94 (SD = 4.13), hand-eye coordination 12.94 (SD = 2.54), and underhand serve ability 6.25 (SD = 1.27). The minimum and maximum values indicate variation in ability among students.

Table 2. Results of the normality test (Kolmogorov–Smirnov)

Variable	Statistic	Sig.	Distribution
Arm muscle strength	0.200	0.001	Not normal
Hand-eye coordination	0.133	0.109	Normal
Underhand serve ability	0.189	0.002	Not normal

Arm muscle strength and underhand serve ability had significance values below 0.05 and were therefore not normally distributed, whereas hand-eye coordination had a significance value above 0.05 and was normally distributed. Because normality was not met for two variables, the Spearman correlation was used.

Table 3. Spearman correlation results (with exact p-values)

Variable pair	r	p-value	Significance
Arm strength – Hand-eye coordination	0.391	0.018	Significant
Arm strength – Underhand serve	0.286	0.091	Not significant
Hand-eye coordination – Underhand serve	0.057	0.741	Not significant

A significant relationship was found only between arm muscle strength and hand-eye coordination ($r = 0.391$; $p = 0.018$). The relationships of arm muscle strength and of hand-eye coordination with underhand serve ability were not significant ($r = 0.286$; $p = 0.091$ and $r = 0.057$; $p = 0.741$, respectively).

Table 4. Results of the multiple linear regression analysis

Variable	B	Std. Error	Beta	t	Sig.
Constant	4.543	1.273	–	3.569	0.001
Arm muscle strength	0.066	0.058	0.215	1.145	0.261
Hand-eye coordination	0.030	0.094	0.059	0.314	0.755

Model summary: $R = 0.255$; $R^2 = 0.065$; adjusted $R^2 = 0.008$; $F(2,33) = 1.14$; $p = 0.330$. Partially, neither predictor significantly influenced underhand serve ability (both Sig. > 0.05). Together, the two variables explained only about 6.5% of the variance in underhand serve ability, and the overall model was not statistically significant, confirming that arm muscle strength and hand-eye coordination do not meaningfully predict underhand serve ability in this sample.

DISCUSSION

These findings offer an important perspective on motor skills in physical education at the elementary-school level. Theoretically, arm muscle strength and hand-eye coordination are often positioned as primary determinants of manipulative skills such as the volleyball serve. However, the results indicate that in elementary-aged children these two components do not yet play a significant role in determining underhand serve success. This does not reject existing theory but rather refines its application to the context of children's motor development.

From a motor-development perspective, elementary-school students are still mastering basic movement patterns and transitioning to sport-specific skills. At this stage, technical mastery, movement understanding, and meaningful learning experiences tend to matter more than physical strength alone (Bartolo et al., 2024). This helps explain why gains in arm muscle strength, as measured by the push-up test, do not translate directly into better underhand serve quality, since general strength does not necessarily align with the biomechanical and coordinative demands of the specific serving movement.

Hand-eye coordination measured by the throw-and-catch test reflects general coordination rather than sport-specific coordination. The underhand serve requires a more complex integration involving footwork, arm swing, body position, and the timing of ball contact (Abid et al., 2025). Good general coordination therefore does not automatically yield an effective serve without adequate technical understanding and practical experience.

These findings extend and synthesise existing studies. Several studies have reported that strength and coordination contribute significantly to serving skills (Ertanto et al., 2021; Setiawan & Mukarohim, 2024; Marwan et al., 2023; Bachtiar & Batennie, 2022), but most were conducted on adolescents, novice athletes, or subjects with prior structured training. In contrast, the present study shows that in elementary-school physical education, pedagogical factors and learning experiences play a more dominant role than purely physical factors, echoing the mixed evidence reported for younger and less-trained groups (Fajar et al., 2023; Firdaus & Fahrizqi, 2023; Rifqi et al., 2025).

These results align with the constructivist and game-based approaches in physical education, which hold that motor skills develop optimally through active, meaningful, and varied learning experiences. Improved motor performance depends less on isolated increases in physical capacity than on how students construct movement understanding through exploration, feedback, and reflection. Similar conclusions were reported by Gustian et al. (2024) and Setiawan et al. (2025), who showed that game-based learning such as Teaching Games for Understanding improves movement performance through motor adaptation and technical understanding rather than through isolated strength or coordination training (Breed et al., 2024; Papagiannopoulos et al., 2023).

From a pedagogical standpoint, the results imply that teachers should not overemphasise isolated strength or coordination drills in underhand serve instruction, but should instead integrate the serve into play activities, modified games, and contextual movement tasks (Indrawathi et al., 2022; Timba & Ritan, 2021). This approach supports the goals of the physical-education curriculum, which emphasise holistic development, active participation, and lifelong learning. Volleyball also remains a valuable means of developing physical attributes across ages (Leung & Shi, 2025), so the point is not to abandon physical preparation but to place it within meaningful, technique-oriented learning.

This study has limitations. First, the instruments measured general strength and coordination and do not fully represent the specific movement demands of the underhand serve. Second, the sample was limited to a single school with a modest size, so generalisation requires caution. Third, the study did not include pedagogical variables such as teaching method, quality of teacher feedback, or students' playing experience, which likely play a substantial role in underhand serve performance and should be examined in future research. Overall, the study contributes to the understanding that improving underhand serve skills is achieved more effectively through a constructive, experiential learning approach than through a focus on the physical component alone. These findings enrich theoretical study and provide practical direction for developing more contextual and meaningful physical-education learning strategies.

CONCLUSION

Arm muscle strength and hand-eye coordination did not have a significant relationship with volleyball underhand serve ability in elementary-school students, either partially or simultaneously, indicating that underhand serve skill in children's physical education is influenced more by pedagogical factors and technical mastery than by physical components alone. The novelty of this study lies in correcting the common assumption that increasing strength and coordination directly improves children's technical sport skills, and in emphasising the importance of the motor-development context. Methodologically, the finding underlines the need for instruments that are more specific to the skill being measured; practically, it suggests that underhand serve learning in elementary schools should focus on active, contextual, and game-integrated movement experiences. Future research is encouraged to examine technical variables, learning methods, and playing experience as the main determinants of students' motor skills.

ACKNOWLEDGEMENTS

The authors would like to thank all parties who supported this study, particularly SD Negeri 13 Tanjungraja for granting access, and the students who participated.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this study.

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