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Temporal dynamics of motor skill acquisition in volleyball forearm self-volleying among PATHFit 4 students at Nueva Ecija University of Science and Technology, Philippines

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ABSTRACT

This study examines the temporal dynamics of motor skill acquisition in volleyball forearm self-volleying among Physical Activity towards Health and Fitness (PATHFit) 4 students at Nueva Ecija University of Science and Technology, Philippines. The study aimed to determine baseline proficiency, monitor changes in performance at 15-minute intervals during a continuous practice session, and establish how age and sex affect skill development. The researchers used a quasi-experimental time-tracking design to assess 123 second-year students through repeated measurements over one hour of instructional time. The results showed a steadily increasing trend, with the greatest improvements observed during the initial stage of cognitive learning. Although male students demonstrated higher absolute performance throughout the period, female students showed greater relative percentage gains during the first interval. Statistical results indicated that sex was significantly associated with performance, whereas age was not. The study concludes that although short-term intensive practice leads to substantial technical improvements, performance plateaus and coordination declines occur towards the end of the hour due to physical fatigue. The study recommends adopting the Temporal Mastery Forearm Proficiency Program to support gender-sensitive instruction and shared learning activities.

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1. Introduction

The evolution of volleyball into a component of physical education programs worldwide demonstrates the recognition of its role in developing physiological potential and psychosocial skills. According to professionals in the international sports community, the art of the forearm pass is the basis for defensive consistency and offensive communication within the team (Yudiana et al., 2022). According to the recent international statistics given by the Volleyball Performance Index, the proportion of individuals who achieve the set standards of technical proficiency is less than one-third of all participants in general sports programs, which suggests that there is a general disparity in the process of developing the foundational motor skills in the early years of engagement in sports activities (Puaben and Poralan, 2025). This international discrepancy highlights the urgent need for evidence-based pedagogical approaches that systematically monitor the long-term development of skills.

In the Philippines, volleyball is not just a form of recreation, but a very strong cultural phenomenon. The sport was introduced to the archipelago by Elwood S. Brown through the Young Men's Christian Association (YMCA) in 1910 and quickly underwent a metamorphosis, becoming part of the backyard and beach life of every island. Filipinos heavily shaped the history of the sport; in 1916, they invented the so-called set-and-spike, or Filipino Bomb, and revolutionized game tactics to keep the game high-intensity and flowing. Despite this rich heritage, modern Philippine physical education faces the challenge of standardizing motor-skill assessment. Ancog (2025) noted that structured interventions significantly improve athletes' serving and passing skills in school-based programs; however, researchers still lack data on the short-term learning curves of non-elite student populations in general education courses such as Physical Activities Towards Health and Fitness (PATHFit). The recent Physical Education (PE) paradigm shift to the

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PATHFit model is an example of a paradigm shift in the Philippine higher education system, as reflected in the CHED Memorandum Order (CMO) number 39, series of 2021. Specifically, PATHFit 4, which focuses on team sports, particularly volleyball, is devoted to holistic development through movement competence, teamwork, and team leadership (Juhrodin et al., 2023).

Nevertheless, the lack of continuous tracking over time within a single instructional session has left educators with minimal information about students' actual development between the first whistle and the conclusion of a one-hour exercise. The literature on the rate of skill improvement at 15-minute intervals has a quantifiable gap, particularly when sex and prior athletic exposure interact. The majority of the research focuses on long-term effects over a few weeks, without considering the short-term physiological and cognitive changes that occur during a single, intensive practice session.

Self-volleying of the forearm is a fidelity diagnostic tool that measures the platform-forming flat plateau formed by the inner forearms when they are clamped at the wrists (Balou et al., 2026). This ability involves coordinating both the lower and upper parts of the body, and leg propulsion and minimal arm swing are the primary criteria for controlling the ball.

This complexity of movement frequently results in high error rates among beginners who are unable to control ball trajectory and sequence movement. These temporal dynamics are vital to the design of successful PE programs to avoid coordination erosion and performance plateaus during the one-hour period, which are common in college physical education classes.

The study will address these gaps by examining forearm self-volleying skills among second-year college students at Nueva Ecija University of Science and Technology (NEUST), San Isidro Campus, Philippines. The experimental practice session will last 60 minutes, during which the researcher will assess students' performance at specific time intervals to identify their learning progress. Specifically, the study aims to:

1. Determine the demographic profile of the student respondents in terms of age and sex.
2. Assess their baseline level of forearm self-volleying proficiency before the practice session.
3. Monitor and compare the number of successful volleys at 15, 30, 45, and 60-minute intervals.
4. Determine whether significant differences exist in performance and improvement rates between male and female respondents.
5. Examine whether significant relationships exist between the respondents' demographic profiles and their baseline forearm self-volleying proficiency and performance at the specified time intervals.
6. Propose a program based on the findings to improve motor skill acquisition in the PATHFit 4 curriculum.

2. Literature review

2.1. Pedagogical models of motor learning in collegiate team sports

The Physical Activities Towards Health and Fitness (PATHFit) model, established in the Philippines under CHED Memorandum Order No. 39, is a conscious effort to organize collegiate movement experiences systematically, with a focus on functional health and physical literacy. PATHFit 4 is designed to develop motor competence and social skills in team games such as volleyball. Traditionally, however, each collegiate teacher has had difficulty addressing wide variations in basic motor skills among the non-elite population. Ancog (2025) found that before attending university, university students had "very poor" basic volleyball skills, suggesting they lacked systematic physical education in childhood.

In an effort to close this baseline gap, physical education programs are moving away from the teacher-led drill-and-practice model. However, contemporary sports pedagogy focuses on student-centered approaches that take into account skill learning alongside contextual understanding. In volleyball, for instance, Juhrodin et al. (2023) showed that life skills (cooperation, communication, emotional regulation) integrated into volleyball training positively influence volleyball execution and motivation over time. Likewise, by employing tools such as the Modified Volleyball Information System (M-VIS), developed by Yudiana et al. (2022), coaches can collect performance data in real time and provide instant, objective feedback. This structured tracking reduces unnecessary cognitive load and helps students transition rapidly from the initial cognitive stage of the movements, in which they are clumsy and highly conscious, to the associative stage, where movement patterns become more automatic and smoother.

2.2. Kinematic coordination and instructional interventions in the forearm pass

The underhand forearm pass is a basic volleyball defense and offense skill, but it is also one of the most challenging skills for beginners to learn. The pass is biomechanically challenging due to the coordination of the upper and lower bodies. The player has to make a stable, flat base and use leg extenders to work the ball; the elbows and wrists must be stable. This "unusual" position typically leads to high error rates among novices. Balou et al. (2026) identified five common technical challenges that beginners struggle with: keeping the ball, body positioning, forearm alignment, leg coordination, and fear of ball impact.

As demonstrated in the previous evaluations, small-sided games and structured drills are a well-balanced method of learning. Although repetitive drills can be used to establish joint angles and platform alignment, game-like play requires students

to continually adjust their footwork and body position (Cruz, 2024). This is a critical variable in developing a flexible motor program. For total novices, using lighter balls with modifications during early training stages can alleviate impact pain and help students concentrate on the correct shot form without being frightened by the impact.

2.3. Interaction of gender, biological maturation, and prior exposure

Physical education teachers need to be aware of how boys and girls learn motor skills to ensure they are teaching a fair and effective PE program. Traditional fitness tests have revealed an "absolute performance gap," with boys' scores higher for speed, explosive power, and upper-body strength. A physiological explanation for this difference is well established. The American College of Sports Medicine consensus statement, published by Hunter et al. (2023), explained that after puberty, hormone changes (especially a 30-fold increase in testosterone in males) cause an increase in muscle fiber size, an increase in the number of Type II muscle fibers, and a decrease in the percentage of body fat. Male students have a distinct advantage in explosive movements such as jumping and spiking due to these biological differences.

These physiological differences also result in different movements in sporting activities. Slovák et al. (2026) suggested that women may change their shoulder and elbow joint angles during arm swing to compensate for lower upper-body strength, while men may opt for a longer lever arm and parallel take-off angles to ensure greater force transfer. Additionally, de la Rubia et al. (2025) reported that physical performance in volleyball is explained more by biological maturation than by chronological age, and that more than 70% of the variance in jump and reach tests is explained.

This absolute performance difference is not solely a result of biology; it is also influenced by prior sports experience and socialization. Young boys have traditionally been encouraged to engage in informal play-based activities that develop ball-handling skills, giving them a "Matthew Effect"—beginning formal physical education with more complex ball-handling skills. But once these unequal entry-level points are accounted for by an Analysis of Covariance (ANCOVA), the gender-based differences in learning rate become quite different. The gender difference in performance evaluation can be minimized or even eliminated after controlling for baseline experience, as Franzen and Wöhner (2026) showed. After the initial training is adjusted for gender, the rate of neuromuscular adaptation to training is quite comparable between men and women.

Indeed, the relative percent gain (RPG) that beginner females typically demonstrate in the first 15 minutes of structured learning is often quite large, especially relative to their starting level (often nearly 99%). Such remarkable growth shows that while there is an absolute difference in performance between males and females, there is a much more equitable difference in the capacity to learn motor skills, and that both sexes can greatly profit from targeted physical education.

2.4. Temporal fatigue dynamics and the degradation of motor control

To design effective learning plans, it is important to know how skills are acquired within a single, continuous practice session. PE classes usually last 60 minutes and are delivered in a linear, 'massed' time format, with the expectation that more practice equals more learning. But sports science studies indicate that after a certain amount of time, a phenomenon called coordination erosion occurs during long training sessions. In the first 30 minutes of a session, students' performance improves quickly (the cognitive stage of learning); however, after 45 minutes, performance gradually decreases, reaching a plateau around 60 minutes.

This late-session drop is not just due to localized muscle fatigue, but a psychobiological reaction to physical and mental stress. A large study by Habay et al. (2025) showed that maintaining a high level of cognitive attention for 45 minutes or more causes acute mental fatigue, which leads to a higher Rate of Perceived Exertion (RPE) and to an impairment of physical performance. In volleyball, this mental fatigue impairs visual tracking and quick decision-making, which are essential for positioning under the ball.

As practice time exceeds 45 minutes, mental and physical fatigue of the shoulder girdle leads to a breakdown in platform geometry and footwork. This is in line with the findings of Behrens et al. (2023) and Pethick and Tallent (2022), who have determined that sustained motor tasks lasting more than 40 minutes consistently lead to a loss of motor control and technical errors. Therefore, it is not beneficial to provide sustained, continuous practice for 60 minutes, as this can lead students to reinforce poor movement patterns due to fatigue. Physical education sessions to maximize learning should be structured to include shorter, spaced-practice blocks and structured active recovery/transitions or low-stress dynamic gameplay at the end of the session.

3. Methods

The research design used was a quasi-experimental time-tracking model. This design enabled the researcher to observe the development of a specific motor skill, the forearm self-volley, within a controlled teaching system, without the random assignment of conditions as in pure experimental designs. The study employed a one-group pre-test/post-test design with repeated measures at 15-minute intervals to record minor changes in performance as the learner advanced from the associative to the cognitive stage of learning. This time series mapping plays a critical

role during the interpretation of the dose-response relation of practice volume and technical proficiency during collegiate physical education.

The participants in this study were second-year college students at the Nueva Ecija University of Science and Technology (NEUST), San Isidro campus, in the province of Nueva Ecija, Philippines. A total of 123 students who participated in the study were officially enrolled in the course PATHFit 4: Team Sports during the second semester of the academic year 2025-2026. Inclusion criteria: students had to be active participants in the normal instructional sessions and have no medical history of conditions that would hinder high-intensity physical activity. The researchers employed purposive sampling to represent the real learning context of the NEUST PATHFit 4 curriculum.

The study employed a two-part instrument as the main data collection tool. The first section was the demographic profile, which included information on sex and age using a structured questionnaire. The second section was the Self-Volleying Performance Record, a systematic tracking sheet in which the researcher and trained assistants documented the baseline data and outcomes of the 15-, 30-, 45-, and 60-minute assessments. The researchers recorded the forearm self-volley as the number of successful contacts in which the ball rose vertically to at least forehead height at a steady rhythm, without hitting the floor or other body parts.

The study was conducted during a predetermined two-hour laboratory session at the university gymnasium to ensure environmental consistency. The following guidelines were observed: a 10-minute standardized dynamic warm-up (light jogging, shuttle running to raise heart rate, and joint-specific exercises, e.g., arm circles and wrist rotations) to prepare the musculature to withstand repeated hits. Then, students were given a baseline test (T0) lasting 1 minute when the 1-hour drill began.

The study protocol required respondents to perform as many forearm self-volleys as possible. The 60-minute practice block commenced when the researcher whistled. Students involved in the self-volleying drill on the forearm remained in motion. The researchers trained respondents to focus on creating a platform, which involves locking the elbows, joining the wrists, and using the legs to generate power. The whistle was blown at 15, 30, 45, and 60 minutes of the session to indicate performance evaluation. In each one-minute trial, the study recorded the number of successful volleys completed by the students. During the inter-assessment sessions, students returned to self-volleying. The researcher offered to insert short hydration breaks into the recording windows; however, they did not encourage students to sit, which could make them stiff. The researcher achieved a 5-minute post-exercise reduction in muscle pain by introducing a 5-minute static stretching cool-down after the 60-minute session. To ensure the reliability of the manual volley counting, all trained research assistants underwent a pre-study calibration session. Inter-rater reliability was assessed using Cohen's Kappa, yielding a value of 0.88, indicating strong agreement in volley counting accuracy.

A variety of statistical procedures were applied to the analysis of the data, which was consistent with the purposes. Descriptive statistics were used to analyze the demographic profile, including frequencies and percentages, and to compute the mean and standard deviation to determine the proficiency of the five recording points. The Repeated Measures ANCOVA method was also used to compare the number of performances across four intervals and determine whether the improvement was significant. To compare performance levels between male and female students, an independent-samples t-test was applied at each interval. Finally, Pearson's r was used to assess the association between the demographic variables and the performance measure.

This study was embedded within an active, intact PATHFit 4 university curriculum, and a randomized control group was not feasible, which constitutes a limitation of the current quasi-experimental design.

4. Results

This research study was conducted among undergraduate students enrolled in the Physical Activity towards Health and Fitness (PATHFit 4). The demographic distribution (Table 1) reveals that there were 123 students, with a significant number of female students who responded (70%) compared to male students (30%). The mean age for the total number of participants is 19.80 ± 1.38 years, with the male group's mean age being 19.70 ± 1.10 years and the female group's mean age being 19.84 ± 1.49 years. Table 2 shows the baseline forearm self-volleying proficiency of undergraduate students by sex. As seen in Table 2, prior to the continuous practice block, baseline proficiency measurements established that the total mean score for male students was 12.32 ± 15.03 successful repetitions within a one-minute trial. The baseline mean of the forearm proficiency for the female students was 4.41 ± 4.26 successful volleys. Table 3 shows the students' progression of successful forearm volleys across intervals. Performance was measured at 15-minute intervals and showed an increase over the one hour for both males and females. Male students' mean score rose from 12.32 to 23.22 ± 25.86, and for female students, the mean score went from 4.41 to 8.78 ± 8.86 between the baseline and the 15-minute mark. By 30 minutes, males reached a mean of 35.35 ± 37.36 and females reached 10.36 ± 07.98. At 45 minutes, male performance hit 41.62 ± 41.21 and females reached 13.93 ± 12.58. The absolute scores were highest at the final 60-minute mark, with scores of 45.41 ±43.33 for males and 15.38 ± 11.94 for females. The same results are reflected in the learning curve progression of forearm volleys between intervals (Fig. 1).

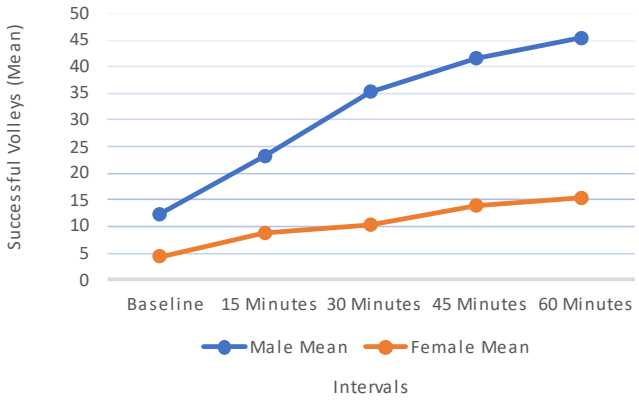


Fig. 1: Learning curve progression of forearm volleys across intervals

Table 1: Demographic profile of the respondents

Variable	Male [n = 37 (30%)] mean ± SD	Female [n = 86 (70%)] mean ± SD	Total (n = 123) mean ± SD
Age	19.70 ± 1.10	19.84 ± 1.49	19.80 ± 1.38

Table 2: Baseline forearm self-volleying proficiency by sex

Variable	Male (n = 37) mean ± SD	Female (n = 86) mean ± SD
Baseline	12.32 ± 15.03	4.41 ± 4.26

Table 3: Progression of successful forearm volleys across intervals

Interval	Male (n = 37) mean ± SD	Female (n = 86) mean ± SD
Baseline	12.32 ± 15.03	4.41 ± 4.26
15 minutes	23.22 ± 25.86	8.78 ± 8.86
30 minutes	35.35 ± 37.36	10.36 ± 07.98
45 minutes	41.62 ± 41.21	13.93 ± 12.58
60 minutes	45.41 ± 43.33	15.38 ± 11.94

Table 4 presents the significant difference in performance between male and female students. As illustrated in Table 4, there were clear differences in absolute point accumulation and relative rates of development. Female students' rate of relative improvement was 99.09% (+4.37 volleys), and male students' was 88.47% (+10.90 volleys), during the first 15 minutes of practice. Between 15 and 30 minutes, males improved by 52.24% (+12.13 volleys) and females by 17.99% (+1.58 volleys). From 30 to 45 minutes, males advanced by 17.74% (+6.27 volleys) and females by 34.46% (+3.57 volleys). In the final window (45 to 60 minutes), gains decelerated to 9.11% (+3.79 volleys) for males and 10.41% (+1.45 volleys) for females. The relative percentage change for overall progress from baseline to 60 minutes was 268.59% for boys and 248.75% for girls.

Table 4: Significant difference in performance between male and female students

Intervals	Male improvement (f)	Male % gain	Female improvement (f)	Female % gain
Baseline to 15 minutes	+10.90	88.47	+4.37	99.09
15 minutes to 30 minutes	+12.13	52.24	+1.58	17.99
30 minutes to 45 minutes	+6.27	17.74	+3.57	34.46
45 minutes to 60 minutes	+3.79	9.11	+1.45	10.41
Total (baseline to 60 minutes)	+33.09	268.59	+10.97	248.75

Table 5 shows the comparison of interval-to-interval progression of self-volleying proficiency. Bonferroni pairwise post hoc comparisons were used to determine the statistical significance of changes between intervals. The change from 15 minutes (Interval 1) to 30 minutes (Interval 2) was statistically significant (Mean Difference = -4.756, p = 0.001, 95% CI [-8.034, -1.478]). Progression from 30 minutes to 45 minutes (Interval 3) also demonstrated statistical significance (Mean Difference = -4.382, p = 0.027, 95% CI [-8.446, -0.318]). No differences were found in the performance change from 45 minutes to 60 minutes (Interval 4) (Mean Difference = -2.154, p = 0.841, 95% CI [-6.046, 1.737]).

Table 5: Comparisons of interval-to-interval progression

(I) time	(J) time	Mean difference (I-J)	Std. error	Sig.[a]	95% confidence interval for difference[a]	
					Lower bound	Upper bound
1	2	-4.756*	1.222	0.001	-8.034	-1.478
	3	-9.138*	1.317	0.000	-12.669	-5.607
	4	-11.293*	1.566	0.000	-15.494	-7.092
2	1	4.756*	1.222	0.001	1.478	8.034
	3	-4.382*	1.515	0.027	-8.446	-0.318
	4	-6.537*	1.450	0.000	-10.425	-2.648
3	1	9.138*	1.317	0.000	5.607	12.669
	2	4.382*	1.515	0.027	0.318	8.446
	4	-2.154	1.451	0.841	-6.046	1.737
4	1	11.293*	1.566	0.000	7.092	15.494
	2	6.537*	1.450	0.000	2.648	10.425
	3	2.154	1.451	0.841	-1.737	6.046

*: The mean difference is significant at the 0.05 level; 1 = 15 Minutes; 2 = 30 Minutes; 3= 45 Minutes; 4 = 60 Minutes; a: Adjustment for multiple comparisons: Bonferroni

Table 6 presents the analysis of covariance (ANCOVA) for post-training skill level. The ANCOVA model was used to hold pre-existing student experience constant by including baseline values as a covariate. Baseline score was also found to significantly influence the final capabilities, explaining 55.6% of the total variation in the capabilities (F (1, 120) = 150.31, p < 0.001, n_p^2 = 0.556). For this covariate, Sex was statistically significant, although the effect size was quite small, accounting for 9.7% of the residual variance (F (1, 120) = 12.84, p < 0.001, n_p^2= 0.097). Age had no statistically significant relationship with the post-test results (F (1, 120) = 0.87, p = 0.353, n_p^2= 0.007).

Table 7 shows the relationship between demographic profile and performance metrics. There was no significant correlation between chronological age and self-volleying performance at baseline (r = 0.025, p > 0.05) or at 60 minutes (r = 0.000, p > 0.05), respectively, when assessed using Pearson correlation tracking. Sex, however, had a significant negative correlation at each evaluation phase (p < 0.01), ranging from r = -0.379 at baseline to r = -0.476 at 60 minutes.

Table 6: ANCOVA for post-training skill level

Source	Type III sum of squares	df	Mean square	F	Sig.	Partial eta squared
Baseline	44326.85	1	44326.85	150.31	0.000	0.556
Sex	3786.47	1	3786.47	12.84	0.000	0.097

Table 7: Relationship between demographic profile and performance metrics

Predictors	BC	15 MC	30 MC	45 MC	60 MC
Age	*r* = 0.025	*r* = 0.021	*r* = -0.015	*r* = 0.063	*r* = 0.000
Sex	*r* = -0.379**	*r* = -0.386**	*r* = -0.474**	*r* = -0.458**	*r* = -0.476**

**: Correlation is significant at the 0.01 level (2-tailed); BC = Baseline Count; MC = Minutes Count

5. Discussion

5.1. Demographic profile of the respondents

The demographics show that there are 123 respondents, with an overwhelming majority (70%) being female. The trend reflects overall enrollment at the NEUST San Isidro campus, where education-related and management programs were more likely to include more females.

The average age of 19.80 years also coincides with young adulthood, when neurological development is almost complete, and people can perfect complex motor patterns. The study by Albaladejo-Saura et al. (2021) indicated that although the biological maturation factor plays a significant role in overall adolescent sports performance, the collegiate age group (19-21) shifts the emphasis to training history and motor educability. The high number of female players highlights changing gender roles in Philippine volleyball, where the sport has become a significant source of female participation. In the Philippines, basketball was a more feminine sport than volleyball, which attracted more female participation. The inclusion of 37 male players (30%), however, reflects the increased popularity of men's volleyball, which has been solidified by the national team's recent international victories. Research undertaken has observed that motivation declines with age as adolescence and adulthood change.

Therefore, the university environment is an ideal opportunity to re-motivate students through structured physical exercise (Antunes et al., 2024; Espada et al., 2023). Moreover, the age group of 18-22 is considered the optimal period for the development of the so-called perceptual-motor ability (crucial for self-volleying), which coordinates the hand and eye.

5.2. Baseline forearm self-volleying proficiency by sex

At study entry, the mean was 12.32 in male students and only 4.41 in female students. Suggate et al. (2025) claimed that high standardized test scores correlate with fine motor control and upper-body mechanisms. In contrast, low scores, such as those recorded by the female cohort, indicate a lack of early exposure to quality physical education. Novices have problems with timing and movement sequence; they often commit gross errors in controlling the ball's trajectory. The very low mean of 4.41 for females, compared with 12.32 for males, can be explained by other factors. The studies show that males are more likely to engage in general sports at an earlier age in school, which results in greater motor preparedness to play ball games (Zheng et al., 2022). In addition, the standard deviation for males (15.03) reflects the large variation in skill level, with some students having vast varsity experience and others being amateurs. This forearm pass is often cited as the hardest move for beginners to master. It requires a complex combination because it requires a particular, counterintuitive ready position (Cruz, 2024). These findings highlight that conditioning and technical practice bridge such initial technical differences, and systematic, task-specific training generally lessens gender differences in motor performance.

5.3. Progression of successful forearm volleys across intervals

The progression of successful forearm volleys across intervals shows a steady positive trend for both groups. The fastest decrease was during the first 30 minutes, and the increase in distance between 12.32 and 23.22 over 15 minutes is nearly 100 percent in males and nearly twice as much in

females (4.41 to 8.78). This finding aligns with the Motor Learning Theory, which emphasizes that, with repeated and intentional practice, neuromuscular control and movement pattern refinement are enhanced (Leech et al., 2022). Nevertheless, the improvement rate started to slow down around 60 minutes.

An example is the female group, which gained an average of 1.45 volleys in the last 15 minutes (13.93, 15.38). These findings imply effects of physical fatigue and the development of the so-called coordination erosion, in which muscles lose their ability to maintain technical accuracy under metabolic stress (Sun et al., 2022). The overall improvement shows that dedicated practice blocks yield technical gains within a single instructional window, despite the 60-minute plateau (Fig. 1).

5.4. Significant difference in performance between male and female students

There was a significant difference in the absolute performance of male students across all intervals compared with the base performance. Biological factors such as body composition—including greater upper-body muscle mass, a higher percentage of Type II muscle fibers, and the profound architectural effects of post-pubertal testosterone—are important drivers behind the forceful, explosive mechanisms required for volleyball (Hunter et al., 2023). However, physical factors are just a part of the equation. These trajectories cannot be understood without analyzing the participants' background and practice history, as well as their socio-cultural contexts. Traditionally, young boys are given much more positive reinforcement, opportunities, and unstructured play development around object-control skills (e.g., throwing, catching, striking) than young girls (Özkan-Kunduracı, 2025). This historical inequity can lead to gender disparities in initial levels of sports engagement and physical activity before formal training begins (Navarro-Patón et al., 2021).

This difference in exposure before the event accounts for the Difference between the percentage and absolute values. In fact, during the first 15 minutes, the percentage jump (the Baseline Floor Effect) was higher for female students (99.09%) than for males (88.47%). Although they have a lower baseline, females possess a significantly larger window for initial adaptation because their starting position leaves a wider landscape for improvement, resulting in a much faster initial rate of sensorimotor adaptation (Listman et al., 2021). Introduced to the basic mechanics of the forearm platform pass, they pick it up fast and learn the initial learning curve quite easily.

Despite this rapid rate of relative improvement, the gap between the genders remained huge after 60 minutes (45.41 vs 15.38 – The Absolute Gap, also called The Motor Ceiling Effect). This is because there is a "ceiling effect" in males that benefits them. The fact that they have a lot of experience with the manipulative means that they have a pre-existing motor schema (movement memories) to which they can quickly get into the basic control and focus their cognitive resources on mastering high-volume consistency (Hirano et al., 2020).

The differences are also reflected in the technical adaptations. To achieve platform stability, females use unique kinematic configurations compared to males, including altering the angles of shoulder flexion and elbow extension to compensate for lower absolute upper-body strength (Slovák et al., 2026). Finally, the larger absolute score difference highlights the need for a gender-specific training paradigm. The training should consider different historical baselines, rather than enforce uniform protocols. With female groups, the fear of ball impact, tracking confidence, and safe progression from technical implementation to overall volume can be mitigated by implementing sex-specific loading or using lighter modified volleyballs.

5.5. Comparisons of interval-to-interval progression

To examine the exact timing of motor skill development and identify any motor skill plateaus, a post hoc analysis was performed using Bonferroni pairwise comparisons. The results show a unique non-linear learning curve with high initial learning and a terminal ceiling effect. There was a significant difference between 15 minutes (Interval 1) and 30 minutes (Interval 2) with regard to successful volleys (Mean Difference = -4.756, $p = 0.001$, 95% CI [-8.034, -1.478]). Performance gains were sustained from 30 minutes to 45 minutes (Interval 3), showing a significant Mean Difference of -4.382 ($p = 0.027$, 95% CI [-8.446, -0.318]). More importantly, the Difference from 45 minutes to 60 minutes (Interval 4) was abrupt, with an improvement to a Mean Difference of -2.154, which did not reach statistical significance ($p = 0.841$, 95% CI [-6.046, 1.737]). Physiologically, these results show that after 45 minutes (the associative phase of motor learning), massed practice beyond this point had little benefit. This performance drop at 60 minutes is explained by acute psychomotor deficits, namely local muscular fatigue of the shoulder girdle and cognitive fatigue from prolonged visual tracking. This path is well supported by recent literature (Behrens et al., 2023). Pethick and Tallent (2022) showed that 40+ minutes of continuous, unconditioned skill blocks typically cause the performance curve to begin to decelerate due to neuromuscular fatigue. In the same way, Fuster et al. (2021) and Conejero Suarez et al. (2020) found that longer volleyball practice sessions without variation result in an accumulation of execution errors, suggesting a need for shorter training sessions. In addition, Habay et al. (2025) found that both cognitive load and attentional fatigue reached a significant peak near the 45-minute mark during new motor tasks, which may explain the immediate performance stabilization ($p = 0.841$) in the final stage of this study.

5.6. ANCOVA for post-training skill level

To test whether there are true gender differences in volleyball player skills, an Analysis of Covariance (ANCOVA) was performed on the 60-minute post-test scores with the baseline scores used as a covariate. This model statistically adjusts for pre-existing recreational experience, so that the final gender analysis is not influenced by baseline recreational experience. The results of the statistics showed that initial capabilities had a significant impact on final performance, with the covariate (Baseline Score) having a very high impact on the final capabilities, $F(1, 120) = 150.31$, $p < 0.001$, accounting for 55.6% of the total variation ($n_p^2 = 0.556$). This balance was achieved, and the main effect of Gender (Sex) was statistically significant, $F(1, 120) = 12.84$, $p < 0.001$; but the practical effect became small ($n_p^2 = 0.097$), accounting for only 9.7% of the remaining variance. Age demonstrated no significant relationship with performance outcomes, $F(1, 120) = 0.87$, $p = 0.353$, $n_p^2 = 0.007$. This research shows that raw post-test differences between sexes overestimate biological differences. The ANCOVA shows that more than half of the performance variance ($n_p^2 = 0.556$) is due to students' entry-level performance abilities, which are significantly influenced by their current formal and informal sports socialization experiences and prior exposure. After this historical advantage is mathematically balanced, the gender contribution is reduced to a minor 9.7% variance, meaning that, when trained from an equal base, the ratio of neuromuscular adaptations between human males and females is quite similar. This is an interpretation that is supported by current sports science research in a nuanced way. Sunda et al. (2022) confirmed this method: When baseline covariates are not included in the analysis of sports skills, the conclusions drawn are essentially based on historical exposure rather than on current ability to learn the skill. This is also supported by findings from Franzen and Wöhner (2026), who found that statistically controlling for initial baseline experiences reduced gender differences in technical execution to either a significant decrease or complete elimination. Lastly, Yao et al. (2025) found that motor pattern stabilization and accuracy tracking were similarly uniform across genders when instruction steps were standardized, again suggesting that gender was a minor predictor of motor skill progression, especially when baseline inputs were held constant.

5.7. Relationship between demographic profile and performance metrics

The statistics indicate that there is no significant correlation between Age and forearm self-volleying proficiency at any point in time during the study. The correlation coefficients did not exceed $r = -0.25$ at baseline and $r = 0$ at the 60-minute point. None of these values were significant ($p > 0.05$). This implies that, in the relatively homogeneous age group of college students, age does not serve as an independent variable in determining the rate of motor skill acquisition or ultimate performance in volleyball. The current findings are similar to those of de la Rubia et al. (2025), who reported that the relative age effects (RAE) tend to weaken with age as the athletes move further into the development journey, where maturity and certain training experience would appear to be stronger predictors of the findings than the birth month or age. Further, as demonstrated by a study by Guerra et al. (2024), in coordination-intensive tasks, such as the forearm pass, physical performance during active engagement and neuromuscular adaptation are more strongly associated with age than with biological age variation. On the other hand, there was a significant and consistent negative correlation between the variable sex and proficiency at every time point ($p < 0.01$). The correlation coefficient ranged from $r = -0.379$ at baseline to $r = -0.476$ at the 60-minute interval. The negative value indicates that male students were generally better at forearm self-volleying, given that the standard code (1s and 2s) is usually male and female, respectively. The fact that the gap is becoming bigger -.379 to -.476 indicates the rate of improvement was steeper among the male participants as the practice session continued. The results are consistent with recent research by Puaben and Poralan (2025), who found that differences in volleyball performance by sex are typically explained by physiological factors, such as upper-limb explosive strength and coordination, which are necessary to control repetitive self-volleying actions. Also, Jariono et al. (2025) observed that in a setting with physical education (such as PATHFit), males tend to start at a higher baseline skill level as a consequence of varying degrees of exposure to prior sports; as a result, they can utilize the available practice time better, a phenomenon also known as the Matthew Effect of skills acquisition.

5.8. PATHFit 4 curriculum motor skill acquisition program: The "temporal mastery" forearm proficiency program (TMFPP)

The researcher suggested the program in the PATHFit 4 curriculum based on the empirical results of the present study, which showed rapid improvement at the beginning, strong gender differences, and a performance plateau towards the end of the session. The TMFPP is a one-hour training program structured to achieve optimal neural recruitment and minimize coordination erosion (see Table 8).

This program should focus only on the technical base. The students toss, catch, and pass on the wall. Visual feedback is given greater importance to ensure that the elbows are locked and the wrists are together. Instructors may use No-sting or lighter volleyballs with females and low-baseline students to minimize impact apprehension and help them

shape the platform appropriately. This stage dwells on movement integration. There will be self-volleying of the shuffle laterally and triangle passing between students and a partner. In men, explosive strength can be enhanced by performing plyometric exercises (e.g., medicine ball throws). It aims to transform the cognitive stage of learning into the associative stage, when movements become smoother.

Active recovery is incorporated to overcome the plateau that was experienced during the last 15 minutes of the session. The drills are then changed to altered mini-games (2v2 or 3v3) with only the forearm pass as allowed contact. It is this contextual interference that causes students to learn movement in a dynamic environment, which is better placed to help them retain the skill in the long term, compared to the repetitive, isolated movements associated with isolated drills. A journal of Motor Progress should be kept by students using the 15-minute tracking method used in this study. Their own improvement curve (e.g., a 99% improvement in the first 15 minutes) will be visualized, helping them become intrinsically motivated and feel a sense of accomplishment.

6. Conclusion

This study provides a comprehensive temporal analysis of the acquisition of motor skills in volleyball amongst college students. The findings prove that: (1) the participants have low levels of forearm passing proficiency, especially in the female group; (2) both groups of sexes realize a significant improvement in the skills in a very brief period of time, indicating the cognitive jump in mastering the skills; (3) the absolute level of performance is much higher in the male group as compared to that in the female group as a result of physiological factors, yet both groups show tremendous improvement on a relative basis; and (5) sex rather than age. These findings highlight the importance of structuring teaching sessions in colleges effectively, including distributed practice and gender-sensitive indicators, so that students can not only train the skill but also learn its mechanics.

Table 8: PATHFit 4 curriculum motor skill acquisition program: The TMFPP

Phase	Objectives	Duration	Focus area	Core activities	Strategies
I. Foundation phase	Correct platform geometry; locking of elbows/wrists; removal of impact-related flinching	0-15 minutes	Technical foundation	"Toss and catch" drills; passing the wall with the static wall.	Females/low-baseline: Use "no-sting" or lighter balls to reduce fear.
II. Integration phase	Switching from cognitive to associative learning, combine footwork with arm-work	15-45 minutes	Movement integration	Lateral shuffle self-volleying; partner "triangle passing."	Males: Sex-appropriate loading (medicine balls) for explosive strength.
III. Dynamic phase	Sustain skill in the face of pressure; movement of processes in a non-linear setting; avoid the erosion of coordination	45-60 minutes	Contextual interference	Modified mini-games (2v2, 3v3); forearm pass as the only contact.	All students: Transition from repetitive drills to dynamic play for long-term retention.
Continuous	Create intrinsic drives; envision improvement curves; determine individual plateaus.	Ongoing	Metacognitive tracking	15-minute interval logging in "motor progress journals."	Self-monitoring: Students visualize their 99% initial gain to build confidence.

List of abbreviations

ANCOVA	Analysis of covariance
BC	Baseline count
CHED	Commission on Higher Education
CI	Confidence interval
CMO	CHED memorandum order
df	Degrees of freedom
MC	Minutes count
M-VIS	Modified volleyball information system
PATHFit	Physical activity towards health and fitness
PE	Physical education
RPG	Relative percent gain
RPE	Rate of perceived exertion
SD	Standard deviation
Sig.	Significance
Std. error	Standard error
T-test	Student's t-test
TMFPP	Temporal mastery forearm proficiency program
YMCA	Young men's Christian association

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Compliance with ethical standards

Ethical considerations

This study received approval from the University Research Ethics Committee (through proper Letter of Approval) and was carried out in compliance with ethical standards for research involving human subjects. All participants signed informed consent forms before the data were collected, and all participants voluntarily participated. Safety practices included warm-up drills and first aid on site. Data were anonymized using coded identifiers and stored securely, and the confidentiality of participants was maintained.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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