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Integrating robotic ball launchers in table tennis: An analytical approach to stroke performance

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Abstract

Limited access to affordable and consistent ball-feeding technology remains a practical challenge for table tennis training in schools and grassroots sports programs, particularly in resource-constrained environments. This study developed and preliminarily evaluated “Robopoly,” a low-cost table tennis ball launcher engineered from repurposed fan motors to support structured technical training. Its novelty lies in a sustainable mechanical design intended as an affordable alternative to commercial robotic systems. The development process included needs assessment, prototype development, expert validation, product refinement, and preliminary field testing. Content validity, assessed by four experts using Aiken’s V Index, yielded a mean score of 0.78, classified as feasible. A pre-experimental one-group pretest–posttest design involving 10 athletes was used to assess forehand and backhand stroke accuracy. The paired-samples t-test indicated improvements in forehand accuracy, $t(9) = -4.25$, $p = .002$, Cohen’s $d = 1.34$, and backhand accuracy, $t(9) = -3.98$, $p = .003$, Cohen’s $d = 1.26$. These findings provide preliminary evidence of short-term improvements in stroke accuracy following the use of Robopoly and indicate its potential to support consistent and repeatable ball-feeding practice in resource-constrained educational and community sport settings. However, the absence of a control group limits causal interpretation. Further controlled studies with larger samples and longer follow-up periods are needed to establish the effectiveness and longer-term training effects of the device.

Keywords: Low-cost ball launcher, robotic training technology, table tennis stroke accuracy, ball-feeding device, table tennis training.

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Authors contribution: a – Preparing concepts; b – Formulating methods; c – Conducting research; d – Processing results; e – Interpretation and conclusions; f - Editing the final version.

INTRODUCTION

Table tennis is one of the fastest racket sports, requiring players to read ball trajectories and execute appropriate strokes within only a few hundred milliseconds. These demands place biomechanical efficiency and perceptual-

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cognitive processing at the center of successful performance. Burns et al. (2020) emphasize the importance of biomechanical efficiency and rapid responses in producing powerful and stable shots, particularly at higher levels of play. From a perceptual perspective, He et al. (2025) highlight the role of visual tracking and eye-hand coordination in helping players anticipate changes in ball trajectory and spin. At the same time, players need precise movement control to execute technical strokes under intense time pressure (Rodrigues et al., 2020). One of the main challenges in actual play is therefore the need to anticipate ball direction and spin from limited pre-contact information while continuously adjusting to changes in an opponent's strategy and tactical patterns (Ji et al., 2023; Rodrigues et al., 2020).

The growing use of technology has opened new possibilities for improving the consistency and quality of table tennis training. Kos et al. (2018) demonstrated the use of video-based and motion-analysis technologies to evaluate stroke mechanics and movement patterns more accurately during training. With a different technological focus, Patil (2024) examined the development of affordable programmable ball-feeding systems capable of delivering balls at more consistent frequencies and trajectories. These developments reflect a broader shift toward training environments that are more structured and supported by measurable information. In this context, robotic ball launchers can provide standardized ball frequency, placement, trajectory, and spin, allowing athletes to repeat technical actions under controlled conditions. Such repetition provides a more consistent training stimulus that may support skill acquisition, stroke consistency, and technical refinement.

However, integrating technology into table tennis training involves more than a device's mechanical capacity to launch balls consistently. It also requires consideration of how athletes respond and adapt to automated training stimuli. Patil (2024), for example, focuses on engineering affordable speed controllers to stabilize ball ejection, whereas D'Ambrosio et al. (2025) examine the cognitive-motor workload athletes experience when adapting to automated frequencies. These different research focuses illustrate how technological development in table tennis training involves both mechanical performance and athlete adaptation. The broader technological evolution has gradually shifted training from unpredictable manual feeding toward more structured and data-driven systems (Supratno et al., 2021). Within such systems, the ability to reproduce different ball behaviors is particularly important. Early robotic simulations could model defensive trajectories such as the backspin chop (Nakashima et al., 2012), while more recent developments have enabled multi-axis spin configurations that reproduce offensive ball characteristics, including those associated with the forehand topspin loop (Ji et al., 2023).

Despite these technological developments, access to advanced training equipment remains uneven. While global trends are moving toward increasingly sophisticated and AI-integrated robotic systems, a considerable technological gap persists in developing regions. In Indonesia, advanced table tennis technology remains largely concentrated in elite national training centers. At the same time, local clubs and schools have limited access to modern equipment because of high procurement and maintenance costs (Erlangga et al., 2022). This creates a practical problem for grassroots athlete development. Although robotic training systems offer opportunities for more consistent and structured practice, commercial equipment is often beyond the financial and technical capacity of schools and local training programs, particularly in resource-constrained and remote areas. This situation highlights the need for affordable, locally adaptable technological solutions suitable for the actual conditions of grassroots training environments (Rudiansyah & Fery Toding Allo, 2023; Syarifatunnisa et al., 2017).

This practical problem was also identified through a preliminary needs assessment conducted in August 2025 at MTs Sunan Kalijaga Brebes. The assessment involved direct observations of table tennis extracurricular training sessions and semi-structured interviews with the coach and 12 student-

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athletes. Three main barriers to skill development were identified. First, training still relied on traditional manual feeding, which did not provide the level of consistency needed for repeated technical practice. Second, the extracurricular program was led by a general physical education teacher without a specialized background in table tennis, creating limitations in the delivery of detailed stroke mechanics instruction. Third, the program had no accessible training technology that could compensate for the absence of a professional feeder. Together, these conditions limited the consistency of the training process and the opportunities available for athletes to develop their technical skills through systematic repetition. The findings therefore indicated a practical need for an automated training device that could be produced and used at a relatively low cost.

Previous studies have examined the contribution of table tennis robots and automated feeding systems to skill development. Patil (2024) demonstrates how automated systems can support more consistent stroke practice, while Erlangga et al. (2022) emphasize the pedagogical value of standardized feeding in school sports settings. Nevertheless, much of the existing research has focused on commercial or technically complex systems that require substantial financial investment and specialized technical support. Research remains limited on low-cost and sustainable innovations that use repurposed materials, such as modified fan motors, to meet practical training needs in resource-constrained environments. More specifically, few studies have provided a technical performance evaluation of locally adaptable systems and their possible association with stroke development among grassroots athletes. Addressing this gap, the present study aims to evaluate the development of “Robopoly” and conduct a preliminary assessment of forehand and backhand stroke performance following its use among school-level athletes.

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METHOD

Research Design

This study adopted the Research and Development (R&D) approach, specifically the model developed by Borg & Gall 1983). In the present study, these stages were adapted to fit the practical constraints of a school-based setting while maintaining the core principles of product development, expert validation, field testing, and iterative revision. The adapted stages included needs analysis, product design, prototype development, expert validation, limited field testing, effectiveness testing, and product revision. To suit the constraints of school-based environments, the original ten stages were followed through to the final product stage, emphasizing iterative feedback from both technical and athletic experts. Click or tap here to enter text. This research includes the stages of needs analysis, design, Robopoly prototype development, expert validation, field testing, and product revision. The effectiveness of the tool was tested through improvements in forehand and backhand table tennis skills. The research steps are presented in Figure 1.

Figure 1. Research steps according Borg & Gall (Borg & Gall, 1983)

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To test the product's effectiveness, this study employed a pre-experimental design, specifically a one-group pretest–posttest design. This approach was selected because of the specific constraints at MTs Sunan Kalijaga Brebes, where the limited number of active athletes (N = 10) made establishing a statistically viable control group impractical. The researchers acknowledge the limitations regarding internal validity inherent in this design. Because there was no control group to account for extraneous variables, such as participants' natural maturation, external physical activities, or the Hawthorne effect, the observed improvements cannot be definitively attributed solely to the Robopoly device. Consequently, the findings are presented as preliminary evidence of the device's potential utility rather than conclusive causal evidence of its training effectiveness.

The research was conducted at MTs Sunan Kalijaga Brebes, focusing on the school's table tennis extracurricular program. A purposive sampling method was used to recruit 10 student-athletes who met the following criteria: (1) active membership in the extracurricular unit, (2) an age range of 13–15 years (M = 14.2, SD = 0.8), and (3) a minimum of one year of basic table tennis experience. None of the participants had prior experience training with robotic ball launchers. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki for research involving human participants. Prior to the commencement of the study, formal institutional permission was obtained from the administration of MTs Sunan Kalijaga Brebes (Document No. 014/K/TS/YDS/II/2025). Because all participants were minors aged 13–15 years, written informed assent was obtained from each athlete, while written informed consent was obtained from their parents or legal guardians before participation. The study procedures also received ethical approval from the relevant institutional review board.

The Robopoly prototype was constructed primarily from plywood and PVC pipe, with several DC motors used to operate the ball launcher, directional launcher, and ball pusher. A battery served as the main energy source for the

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device's mechanical systems. PVC pipe was used as the main support structure, while an on/off control switch regulated the ball's launch angle and pushing mechanism. The device also incorporated a 5-liter (20 cm) plastic bucket. The resulting product was named “Robopoly,” which stands for “robot ping pong only.” The product was developed to provide a more accessible and affordable technological solution for table tennis training. An initial design sketch of Robopoly is presented in Figure 2.

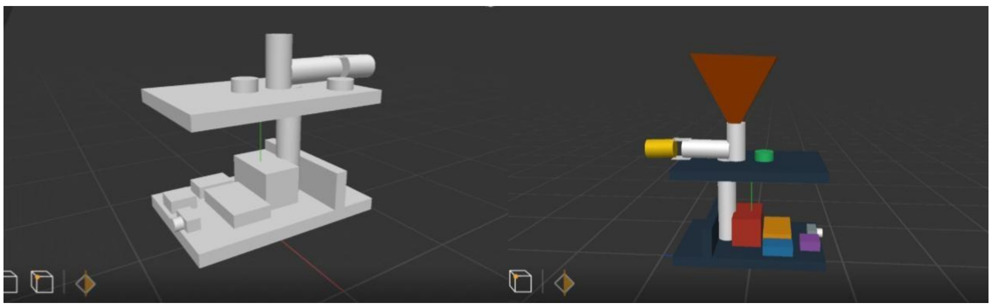

Figure 2. Prototype of Robopoly

Participants and Experts

The product feasibility was assessed by four purposively selected validators: two sports coaching experts (subject matter) and two engineering/technical experts (media). For the field trials, 10 table tennis athletes from MTs Sunan Kalijaga Brebes were recruited using a purposive sampling technique, focusing on those actively participating in the school’s extracurricular program.

Instrument and Data Collection

1. **Content Validity**

   To evaluate the "Robopoly" prototype, a structured questionnaire using a 4-point Likert scale (1 = Very Poor to 4 = Very Good) was employed. To ensure psychometric robustness beyond simple percentages, Aiken’s V Index was used to calculate the content validity coefficient. The formula used was:

$$V = \frac{\sum s}{[n(c-1)]}$$

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Where, is the number of experts, and is the highest scale value. The resulting coefficients were then interpreted using Aiken's V feasibility intervals presented in Table 1.

Table 1. Product eligibility criteria using Aiken's V Index

Score Average Interval	Interpretation
0.80 < ≤ 1.00	Highly Feasible
0.40 < ≤ 0.80	Feasible
0.20 < ≤ 0.40	Sufficient
0.00 < ≤ 0.20	Infeasible

(Saifuddin Azwar, 2018; Suharsimi Arikunto, 2017)

1. **Technical Performance Instrument**

The technical proficiency in forehand and backhand strokes was evaluated using a specialized Target Accuracy Test. The instrument was adapted from the multiball target-accuracy protocol developed by Falahi and Andrijanto (2019). The original manual feeding procedure was modified by replacing the human feeder with the Robopoly device to ensure standardized ball frequency, trajectory, and delivery consistency during testing. The scoring system and target-zone structure remained unchanged from the original protocol.

Procedure: Each athlete performed a total of 20 strokes, consisting of 10 forehand and 10 backhand deliveries launched by the Robopoly device at a constant frequency and speed.

Scoring and Construct Validity: The opponent's court was divided into specific scoring zones (1, 2, and 3 points) based on the strategic difficulty of ball placement. Scoring validity was supported by the target-accuracy framework adapted from Falahi & Andrijanto (2019), who used zone-based ball placement assessment to evaluate technical stroke proficiency in table tennis. The instrument assumes that successful performance is reflected in the athlete's ability to consistently direct the ball toward predefined target areas of varying strategic value. Therefore, the

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construct measured in this study represents technical accuracy and ball-placement proficiency under standardized playing conditions.

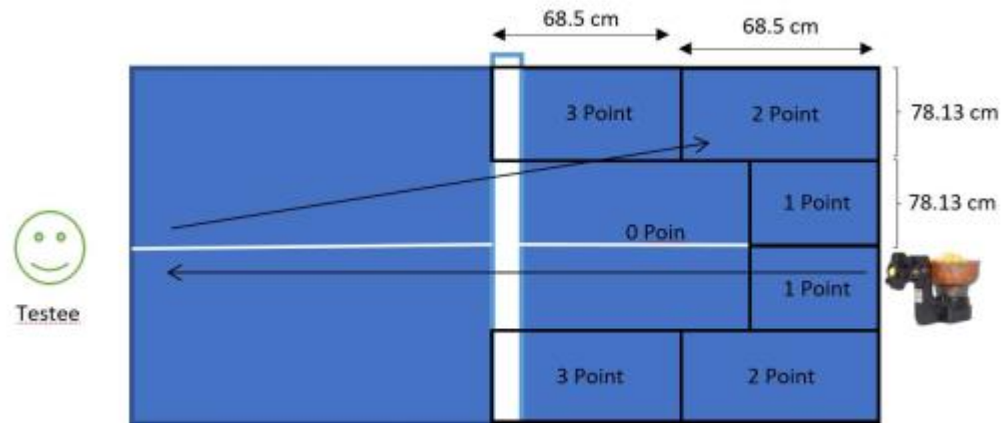

Figure 3. Table Marker of Forehand and Backhand Accuracy Test (Falahi & Andrijanto, 2019)

Data Collection: The total score for each stroke type (maximum 30 points per category) was recorded during the pre-test and post-test sessions to determine the improvement in technical consistency.

Reliability: To ensure data stability, inter-rater reliability was assessed between two nationally certified coaches. Working independently and without conferring, both coaches scored each of the 20 strokes per athlete by assigning the 1-, 2-, or 3-point value of the target zone the ball landed in, and they repeated this procedure across the pre-test and post-test sessions. Agreement between the two raters was then quantified using a two-way mixed-effects, absolute-agreement intraclass correlation coefficient. The results yielded an Intraclass Correlation Coefficient (ICC) of 0.89, indicating "Excellent" consistency in scoring across sessions (Koo & Li, 2016).

Statistical Analysis: Data were analyzed using a paired-samples t-test to determine the mean differences between pre-test and post-test scores. Results are reported using the paired-samples t-test format, including the t statistic, degrees of freedom (df), p values, 95% confidence intervals (95% CI), and Cohen's d effect sizes. Before inferential analysis,

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the normality assumption was assessed using the Shapiro–Wilk test. All analyses were conducted at a significance level of $\alpha = .05$.

RESULT

Expert Validation Result

Four experts evaluated the feasibility of Robopoly. To ensure psychometric robustness, the scores were analyzed using Aiken's V index to determine content validity. The results of the expert validation are presented in Table 2.

Table 2. Expert Validation and Aiken's V Analysis

Expert	Score Obtained	Max Score	Aiken's V	Category
Technical Expert 1	30	48	0.63	Feasible
Technical Expert 2	38	48	0.79	Feasible
Coaching Expert 1	40	48	0.83	Highly Feasible
Coaching Expert 2	42	48	0.88	Highly Feasible
Average	37.5	48	0.78	Feasible

Qualitative feedback from experts highlighted the need for improved consistency in ball ejection, as the prototype's non-computerized mechanism occasionally led to interrupted ball flow when the funnel was overloaded. These issues were addressed in the second revision (Figure 4 & figure 5).

Figure 4. Rebopoly before revision

Figure 5. Robopoly after revision

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Normality test result

The distribution of the data was assessed using the Shapiro-Wilk test. The analysis showed that the scores for both forehand and backhand strokes followed a normal distribution, with the following values: forehand pre-test ((10) = 0.912, = .295), forehand post-test ((10) = 0.934,= .482), backhand pre-test ((10) = 0.908,= .268), and backhand post-test ((10) = 0.925, = .391). Given that all p-values exceeded the significance threshold of .05, the assumption of normality was met, and the subsequent analysis proceeded with parametric procedures.

Table 3. Normality Test (Shapiro-Wilk)

Variable	Statistic	df	Sig. (p)	Conclusion
Forehand (Pre-test)	0.912	10	0.295	Normal
Forehand (Post-test)	0.934	10	0.482	Normal
Backhand (Pre-test)	0.908	10	0.268	Normal
Backhand (Post-test)	0.925	10	0.391	Normal

Performance Analysis

Table 4 presents the descriptive statistics for forehand and backhand stroke scores. The mean score for the forehand stroke was 68.30±2.45 at pre-test and 71.70±2.10 at post-test, representing a raw gain score of 3.40. For the backhand stroke, the mean score was 63.80±2.60 at pre-test and 67.10±2.35 at post-test, representing a raw gain score of 3.30.

Table 4. Descriptive Statistics of Stroke Performance

Variable	Mean Pre-test	Mean Post-test	Raw Gain Score
Forehand	68.30 (2.45)	71.70 (2.10)	3.4
Backhand	63.80 (2.60)	67.10 (2.35)	3.3

Inferential Statistics

The hypothesis testing was conducted using a paired-samples t-test to determine the mean differences between pre-test and post-test scores for both stroke types. The statistical results, including the p-value, degrees of freedom, t-value, 95% Confidence Interval (CI), and Cohen’s d for effect size, are presented in Table 5.

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Table 5. Paired Sample t-test Results (N = 10)

Variable	Mean Diff.	*t*	*df*	-value	95% CI [LL, UL]	Cohen'sd
Forehand	3.4	-4.25	9	0.002	[1.59, 5.21]	1.34
Backhand	3.3	-3.98	9	0.003	[1.42, 5.18]	1.26

For forehand stroke performance, the analysis showed a statistically significant difference between sessions (9) = -4.25, p = .002, 95% CI [1.59, 5.21], d = 1.34. Similarly, for backhand stroke performance, a significant difference was observed, (9) = -3.98, p = .003, 95% CI [1.42, 5.18], d = 1.26.

DISCUSSION

This study evaluated "Robopoly," a low-cost table tennis ball launcher, focusing on its technical feasibility and potential to support stroke mechanics training. The integration of engineering principles with sports pedagogy resulted in a device that met the content-validity criterion of "Feasible" (mean Aiken's V = 0.78). Numerical improvements followed the intervention in both forehand and backhand performance. However, these findings need to be interpreted within the context of motor learning, the characteristics of the training stimulus provided by the device, and the methodological limitations of the study.

The present study found mean improvements of 3.40 points for forehand performance and 3.30 points for backhand performance following the intervention period. These changes were accompanied by large within-group effect sizes for both forehand (Cohen's d = 1.34) and backhand performance (d = 1.26), indicating substantial differences in performance scores between measurement sessions. The observed changes may be associated with the structured and repetitive practice conditions provided by Robopoly. The device delivers a consistent ball-feeding stimulus that enables athletes to repeat stroke movements under controlled conditions. From a motor learning perspective, repeated practice can help learners stabilize movement patterns and develop greater consistency in skill execution, particularly during the initial stages of acquisition (Magill & Anderson, 2021). At the same time, the

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effectiveness of a practice condition depends on the interaction between the learner's skill level, task difficulty, and the amount of information that can be processed during practice (Beik & Fazeli, 2021). In the context of the present study, the predictable feeding pattern provided by Robopoly may have created a manageable level of task difficulty for school-level athletes who were still developing basic forehand and backhand consistency. However, because the study employed a one-group pretest–posttest design without a comparison group, the observed improvements should be interpreted cautiously and cannot be attributed exclusively to the use of Robopoly.

The role of Robopoly can also be understood through the relationship between practice consistency, variability, and contextual interference. The contextual interference literature suggests that the organization of practice influences skill acquisition, retention, and transfer, although the effects of different practice schedules depend on task complexity and learner characteristics (Moretto et al., 2018). Newell (2020) further argued that principles derived from relatively simple motor tasks do not necessarily generalize directly to complex skill learning, indicating that practice conditions need to be considered in relation to the demands of the skill being learned. Robopoly currently provides low-variability, consistent ball delivery, whereas more advanced ball-launching systems can systematically manipulate speed, direction, spin, and placement. For example, Dittrich et al. (2023) demonstrated that a programmable table tennis ball launcher can reproduce controlled variations in trajectory, speed, and spin, illustrating the technological possibilities available in more advanced systems. The present prototype does not offer the same level of variability. However, its simpler and more predictable feeding characteristics may provide an appropriate starting point for athletes who are still developing stable stroke patterns.

Within this context, the low-variability characteristics of Robopoly should not be interpreted as an alternative to variable or game-based practice. Instead, the device may serve as an initial training tool within a progressive

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practice structure. Nur et al. (2024) challenge point framework suggests that learning is influenced by the relationship between task difficulty and the learner's current skill level. Practice conditions that are too difficult may exceed the learner's capacity to process relevant information, whereas conditions that provide an appropriate level of challenge may better support learning. This perspective is relevant to the present findings because the participants were school-level athletes training in a setting with limited access to specialized coaching and technological support. Under these conditions, consistent ball delivery may allow athletes to concentrate on racket position, timing, movement coordination, and stroke execution before progressing toward less predictable practice situations.

This interpretation is consistent with the findings of Syarifatunnisa et al. (2017), who reported that structured mechanical aids may support improvements in stroke accuracy among novice table tennis players. In a related context, Rudiansyah and Fery Toding Allo (2023) highlighted the value of repeated technical practice in resource-limited training environments. The findings of the present study therefore provide contextual support for the potential use of Robopoly in grassroots table tennis training. The device offers athletes opportunities to perform repeated forehand and backhand strokes against a relatively stable stimulus, which may help them focus on consistent technical execution. Nevertheless, progression toward variable ball placement, speed, and spin remains important because competitive table tennis requires continuous adaptation to changing trajectories and playing situations. The value of Robopoly should therefore be understood primarily in relation to foundational technical practice rather than as a complete replacement for coach-led drills, partner practice, or variable match-like training.

The performance gains observed in this study also need to be considered in relation to the specific role of automated ball delivery. A key characteristic of ball-launching technology is its capacity to produce repeated trajectories with greater consistency than naturally occurring rally situations. The development

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of advanced launchers such as AIMY demonstrates how automated systems can generate reproducible trajectories while allowing systematic adjustment of ball speed, direction, and spin (Dittrich et al., 2023). Although Robopoly is mechanically simpler, both systems share the basic principle of providing repeatable ball delivery. In the present study, this repeatability may have increased the number of opportunities available for athletes to practice the targeted forehand and backhand actions under similar conditions. However, because the present study did not directly compare Robopoly with AI-integrated systems, commercial robots, or manual feeding methods, no claim of relative superiority can be made. Its practical value lies instead in its capacity to provide a standardized and repeatable training stimulus in settings where more advanced systems are unavailable.

A key contribution of this research is the technology's accessibility. The production cost of the Robopoly prototype was approximately IDR 500,000 to 750,000, primarily using plywood, PVC pipes, and a repurposed fan motor. For comparison, a market survey conducted in January 2026 using commercially available table tennis robots listed on major Indonesian online marketplaces showed that entry-level robotic systems were typically priced between IDR 3,000,000 and IDR 7,000,000, depending on their features and level of automation. This difference represents a cost reduction of approximately 80–90% compared with commercial alternatives. The affordability of Robopoly is particularly relevant to schools and small clubs where access to specialized training technology is limited. In this respect, the device's contribution lies not in matching the technological sophistication of advanced robotic systems, but in translating the basic function of standardized ball delivery into a form that is more accessible within resource-constrained training environments.

From an engineering perspective, Robopoly introduces a low-cost mechanical innovation by repurposing high-torque DC motors from household fan units into a synchronized ball-launching system. Unlike advanced robotic launchers that integrate programmable control systems to manipulate several

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ball characteristics, Robopoly uses a manual-analog control system that allows launch frequency and ball velocity to be adjusted independently through a customized pulse-width modulation (PWM) circuit. This configuration enables variable speed settings and allows the device to deliver between 20 and 50 balls per minute. The technical approach reflects a different development priority from sophisticated programmable launchers, which emphasize high-fidelity control of speed, spin, orientation, and trajectory (Dittrich et al., 2023). Robopoly instead prioritizes functional simplicity, locally available components, and affordability while retaining the basic capacity to provide repeated ball-feeding stimuli for school-level training.

The findings also suggest several directions for further development of the prototype. Motor learning literature indicates that practice conditions should evolve as learners become more skilled and capable of responding to greater task demands (Guntoro et al., 2020). Therefore, future versions of Robopoly could progressively incorporate greater variability in ball placement, frequency, speed, or spin. Such development would allow the device to support a broader progression from stable technical repetition toward more demanding practice conditions. This direction is consistent with developments in programmable ball-launching technology, where control over trajectory complexity allows training conditions to be adjusted systematically (Dittrich et al., 2023). Nevertheless, these possibilities represent directions for future development rather than functions evaluated in the current prototype.

Despite the observed trends, the study's reliance on a pre-experimental one-group design presents significant threats to internal validity. Without a control group, changes in performance cannot be exclusively attributed to Robopoly because confounding variables, including the natural maturation of the athletes, external physical activities, and the Hawthorne effect, may have influenced the outcomes. Furthermore, the small sample size (n = 10) limits the statistical power and external validity of the findings. The large within-group effect sizes therefore indicate the magnitude of differences between

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measurement sessions but should not be interpreted as evidence that Robopoly alone caused the observed changes. Future research should examine the device using stronger experimental designs, larger samples, and comparison conditions involving manual feeding or other training approaches. Retention and transfer tests would also be valuable for determining whether performance changes are maintained over time and transferred to more variable playing conditions. Consequently, the present results should be viewed as preliminary evidence of the device's potential utility rather than a definitive claim of causal effectiveness.

CONCLUSION

This study developed and preliminarily evaluated "Robopoly," a low-cost table tennis ball launcher constructed from repurposed materials as an affordable alternative to commercial training robots for grassroots athletic programs. The results indicated improvements in both forehand and backhand stroke performance, with mean gains of 3.40 and 3.30 points, respectively, accompanied by large within-group effect sizes. These findings suggest that the device may have practical value in supporting technical consistency in resource-constrained training environments. In particular, consistent and repeatable ball delivery can provide structured opportunities for novice athletes to practice and stabilize basic stroke mechanics repeatedly. However, the observed gains should be regarded as preliminary evidence of the device's potential utility rather than definitive evidence of causal effectiveness, particularly because the study did not directly examine stages of motor learning or long-term skill retention. This study contributes to sport technology development by providing an affordable and locally adaptable training device that can widen access to structured stroke practice for schools and small clubs with limited resources. Nevertheless, the pre-experimental design, small sample size, and short intervention period limit the strength and generalizability of the findings. Longer randomized controlled trials with larger samples and

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extended follow-up periods are therefore needed to establish the sustained effectiveness of this low-cost innovation for athletic development.

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