Indonesian Journal for Physical Education and Sport
https://journal.unnes.ac.id/sju/index.php/inapes
e-ISSN 2774-4434 | inapes@mail.unnes.ac.id
https://doi.org/10.15294/inapes.xxxx

Development and Effectiveness of a Reaction Light-Based Hand-Eye Coordination Training Module in Badminton Athletes

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Received: 15 April 2026 **Accepted:** 28 April 2026 **Published:** 13 May 2026

Abstract
Despite the growing demand for effective and measurable training methods in sports, coordination training in badminton is still largely dominated by conventional approaches that lack variability and objective evaluation. This study aimed to develop and evaluate the effectiveness of a reaction light-based hand-eye coordination training module for badminton athletes. The research employed a Research and Development (R&D) approach using an embedded mixed-methods design, integrating quantitative and qualitative data. The effectiveness of the module was assessed using a one-group pretest-posttest design involving 12 badminton athletes. The results showed a significant improvement in athletes' performance ($p < 0.05$), indicating that the developed module effectively enhances hand-eye coordination. The use of dynamic and randomized visual stimuli through reaction light technology enables a more adaptive, responsive, and measurable training process. These findings highlight the importance of integrating perceptual-motor principles into structured training programs. This study concludes that the developed module provides an innovative, practical, and data-driven approach to improving badminton performance while bridging the gap between sport science theory and real-world training application.

Keywords: hand-eye coordination; reaction light; badminton; training module; reaction time

1. Introduction

Despite the increasing demands for effective and measurable training methods in modern sports, many training practices in the field still rely on conventional approaches that lack variability and objective evaluation. The advancement of science and technology in the field of sports has significantly transformed the paradigm of athlete development, shifting from traditional methods toward more integrated, science- and technology-based training systems (Haekal & Basri, 2021). In modern sports science, athletic performance is no longer viewed solely as the result of physical abilities, but rather as the outcome of complex interactions among physical, cognitive, and neuromuscular components (Nulhadi et al., 2022). This integrated approach emphasizes the importance of coordination as a fundamental element in producing effective and efficient movement.

One of the sports that highly depends on coordination ability is badminton. As a fast-paced and dynamic sport, badminton requires athletes to perform rapid and precise movements in response to continuously changing situations (Adi S, Wahyu Arbanisa, 2023; Hasanuddin et al., 2023). The shuttlecock can travel at extremely high speeds, reaching over 300 km/h at the professional level, which demands quick perception, accurate timing, and precise motor responses (Aliriad, Adi, et al., 2024). In this context, hand-eye coordination becomes a critical factor that directly influences shot accuracy, reaction speed, and decision-making during gameplay.

Hand-eye coordination refers to the ability to integrate visual information with motor actions in a precise and directed manner (Cahyaningrum & Cahyono, 2023). Physiologically, this ability involves the interaction between the visual system, central nervous system, and musculoskeletal system, which work simultaneously to produce appropriate motor responses (Camalis et al., 2021; Finishia & Adi, 2025). Previous studies have demonstrated that hand-eye coordination is significantly associated with technical skills and performance outcomes in badminton (Juni et al., 2023; Sutirta et al., 2022). However, these studies have predominantly focused on examining correlations between variables rather than developing practical and structured training interventions that can be directly applied in training settings.

In practical settings, training methods for improving coordination are still largely dominated by conventional approaches, such as ball-throwing drills and manual reaction exercises (Bahtiar et al., 2023). Although these methods can improve basic coordination skills, they often lack stimulus variability and fail to replicate the dynamic nature of real-game situations (Febrianto et al., 2026). Furthermore, training evaluation is frequently conducted subjectively, making it difficult to measure athlete progress accurately and systematically (Almira Azzaria et al., 2023). This indicates a gap between the demands of modern, science-based training and their implementation in the field.

The integration of technology into sports training provides a promising solution to this problem (Lailani et al., 2026; Soenyoto et al., 2025). One of the emerging approaches is the use of visual stimulus-based training tools, such as reaction light systems, which are designed to improve reaction time and coordination through randomized and dynamic visual cues (Theofilou et al., 2022). This type of training not only enhances motor response but also improves cognitive aspects such as focus, attention, and decision-making ((Adi S et al., 2025; Miswangga et al., 2025). Additionally, reaction light technology enables objective measurement of performance, allowing coaches to monitor athlete development more accurately and systematically.

Despite its potential, the application of reaction light technology in structured training programs remains limited, particularly at the club level (Kusuma et al., 2025). Many training programs still rely on traditional methods and have not fully integrated technology-based approaches into systematic training modules (Artazila & S, 2024). Moreover, existing studies rarely focus on the development of practical training products that are both structured and empirically tested for effectiveness (Yuwono et al., 2025). This highlights a clear research gap, particularly in the development of technology-based training modules that are applicable, measurable, and scientifically validated.

Therefore, this study aims to develop and examine the effectiveness of a reaction light-based hand-eye coordination training module for badminton athletes. The novelty of this study lies in the integration of structured training principles with technology-based visual stimuli, resulting in a training module that is not only theoretically grounded but also practically applicable and empirically tested. The findings of this study are expected to contribute to the advancement of sports training methods and provide an innovative solution for improving athlete performance in a more effective, adaptive, and data-driven manner.

2. Method

This study employed a Research and Development (R&D) approach using an embedded mixed-methods design, in which quantitative data served as the primary component and qualitative data functioned as a complementary component to support product evaluation (Riaz & Shamim, 2026). The quantitative approach was used to test the effectiveness of the developed training module, while the qualitative approach was applied to evaluate feasibility, usability, and user acceptance.

The development procedure was adapted from the Borg and Gall model and simplified according to the research context. The stages included: (1) needs analysis, (2) product design, (3) expert validation, (4) initial revision, (5) small group trial, (6) product revision, (7) effectiveness testing, and (8) final product development (Ade Rahayu, 2025; Siregar, 2025). This iterative process ensured that the developed module met the criteria of validity, practicality, and effectiveness.

The needs analysis stage was conducted through observations and interviews with coaches and athletes at PB ALTREC to identify problems in the training process. The findings indicated that coordination training was still dominated by conventional methods, lacked stimulus variability, and did not provide objective performance evaluation. Based on these findings, a technology-based training module was developed to address these limitations.

The product developed in this study was a structured hand-eye coordination training module based on reaction light technology . The module was designed according to fundamental training principles, including specificity, progression, and variation, to ensure systematic improvement in athletes' performance (Bhakti et al., 2024; Rodríguez et al., 2024). The training program consisted of ten exercise variations adapted to badminton movement characteristics.

The exercise variations included: (1) wall-based hand reaction drills using light stimuli, (2) color-coded visual response exercises, (3) reaction light combined with ball throwing and catching, (4) rotational body movement reaction drills, (5) lateral movement response exercises, (6) multi-directional light response drills, (7) reaction tasks with movement transitions, (8) combined footwork and light stimulus exercises, (9) dual-task reaction exercises, and (10) progressive reaction speed training. All exercises were designed to improve coordination, reaction time, and motor accuracy under conditions simulating real-game situations.

The study was conducted at PB ALTREC, Semarang, Indonesia, involving 12 badminton athletes selected through purposive sampling based on their active participation in training sessions. All participants were involved in both the development and effectiveness testing phases.

To evaluate the effectiveness of the training module, this study employed a one-group pretest-posttest design to measure changes in athletes' performance before and after the intervention. The intervention was conducted over six training sessions, during which athletes performed structured exercises using reaction light stimuli.

The instrument used in this study was a reaction light-based wall toss test to measure hand-eye coordination, reaction time, and response accuracy. In addition, a questionnaire adapted from the Athlete Safety and Training Acceptability Questionnaire (ASTAQ) was used to assess feasibility,

safety, and user acceptance. Documentation in the form of photos and videos was also used to support data validity.

Data were analyzed using descriptive statistics and a paired sample t-test to determine significant differences between pretest and posttest results. Qualitative data from the questionnaires were analyzed to provide additional insights into user experience, feasibility, and the practicality of the developed training module.

The final product of this study is a validated, structured, and practically applicable training module that can be directly implemented in badminton training practice.

3. Result

The product developed in this study is a reaction light-based hand-eye coordination training module designed specifically for badminton athletes. The module integrates structured training principles with dynamic visual stimuli to improve coordination, reaction time, and motor accuracy. It consists of ten systematically designed training variations, complete with implementation guidelines, training objectives, and evaluation indicators, making it applicable in real training settings.

The visual appearance of the developed module is presented in Figure 1.

Figure 1. Cover of the reaction light-based hand-eye coordination training module

The results of this study indicate that the reaction light-based hand-eye coordination training module is effective in improving badminton athletes' performance. The analysis was conducted systematically, including instrument quality testing, assumption testing, and hypothesis testing.

Table 1. Instrument validity results

Item	r-value	Sig.	Description
P1 – P10	0.584–0.895	<0.05	Valid

Note: Items are considered valid if Sig. < 0.05.

The validity test results indicate that all instrument items meet the required validity criteria, confirming that the instrument is appropriate for measuring the intended construct.

Table 2. Reliability test results

Cronbach's Alpha	Description
0.879	Reliable

The reliability test demonstrates a high level of internal consistency, indicating that the instrument provides stable and consistent measurements.

Table 3. Normality test results

Method	Sig.	Description
Shapiro-Wilk	0.106	Normal

Note: Data are normally distributed if Sig. > 0.05.

The normality test indicates that the data are normally distributed, satisfying the assumption required for parametric statistical analysis.

Table 4. Homogeneity test results

Method	Sig.	Description
Based on Mean	0.001	Not homogeneous
Based on Median	0.037	Not homogeneous
Based on Median (adjusted)	0.048	Not homogeneous
Based on Trimmed Mean	0.002	Not homogeneous

Note: Data are homogeneous if Sig. > 0.05.

The homogeneity test indicates that the data variance is not homogeneous. However, this does not affect the analysis, as the paired sample t-test focuses on within-subject comparisons rather than between-group variance.

Table 5. Paired sample t-test results

Variable	Mean Pretest	Mean Posttest	t-value	Sig. (2-tailed)
Pretest–Posttest	7.17	8.67	-3.458	0.005

Note: H_0 is rejected if Sig. < 0.05.

The results of the paired sample t-test indicate a significant difference between pretest and posttest scores ($p < 0.05$), demonstrating that the intervention had a significant effect on athletes' performance.

This finding confirms that the reaction light-based training module effectively improves hand-eye coordination in badminton athletes. The observed improvement suggests that the use of dynamic

visual stimuli contributes to enhanced motor response and performance compared to pre-intervention conditions.

4. Discussion

This study aimed to examine the effectiveness of a reaction light-based hand-eye coordination training module in badminton athletes. The findings indicate an improvement in coordination ability following the intervention, suggesting that the developed training module is effective in enhancing athletes' motor performance.

From a scientific perspective, this improvement can be explained through the mechanism of visual-motor coordination, which involves the integration of the visual system, central nervous system, and musculoskeletal system in producing fast and accurate motor responses (Adi S et al., 2025). This process can be further understood through the concept of neuroplasticity, where repeated exposure to task-specific and dynamic stimuli leads to adaptive changes in neural pathways, enhancing the efficiency of sensorimotor processing. Reaction light-based training provides dynamic and randomized visual stimuli, requiring athletes to process information rapidly and respond appropriately. This repeated interaction between stimulus and response promotes neuromuscular adaptation and strengthens neural connectivity, resulting in improvements in reaction time and movement accuracy.

Furthermore, the effectiveness of this training can also be interpreted through the framework of perception-action coupling, which emphasizes the continuous interaction between perceptual input and motor output. In this context, athletes actively integrate visual information with movement execution in real time. The use of unpredictable visual stimuli in reaction light training enhances this coupling process, enabling athletes to develop faster, more adaptive, and context-specific motor responses during gameplay.

The results of this study are consistent with previous research indicating that hand-eye coordination plays a crucial role in improving technical skills and overall performance in badminton. Athletes with better coordination tend to demonstrate higher shot accuracy, faster responses, and more effective decision-making during gameplay (Hasanuddin et al., 2023). These findings reinforce the role of coordination as a key determinant of performance in badminton.

In addition, the effectiveness of the training module is influenced by the application of fundamental training principles, including specificity, progression, and variation. Exercises designed to reflect game situations enable better transfer of skills into actual performance (Rodríguez et al., 2024). The use of varied and technology-based stimuli also increases athlete engagement and reduces monotony often found in conventional training methods (Jiddan & Adi, 2025).

Compared to traditional training approaches, reaction light-based training offers advantages in terms of stimulus variability and objective measurement. Conventional drills tend to be repetitive and less adaptive to dynamic game conditions (Horváth et al., 2022; Rafi Tri Indarwan & Adi S, 2025). In contrast, randomized visual stimuli improve responsiveness and adaptability in complex situations (Cahyati et al., 2025). Furthermore, this technology enables data-driven performance evaluation (Dwi & S, 2025).

This study also contributes practically by developing a structured and applicable technology-based training module. Unlike previous studies that primarily focus on correlational analysis, this study provides a validated training product that can be directly implemented in coaching practice (Aliriad, S, et al., 2024; Hassan, 2025).

However, this study has several limitations, including a relatively small sample size and the absence of a control group. Therefore, future research is recommended to employ more rigorous experimental designs and larger samples to enhance the generalizability of the findings.

5. Conclusion and Recommendation

This study concludes that the reaction light-based hand-eye coordination training module is effective in improving badminton athletes' coordination ability and visual response. The integration of technology into training enables the creation of a more adaptive, varied, and sport-specific training environment that aligns with the dynamic characteristics of badminton.

From a conceptual perspective, this study operationalizes perceptual-motor integration theory into a structured and applicable training module. The module not only strengthens the relationship between visual perception and motor response but also bridges the gap between theoretical frameworks and practical implementation in sports training.

Practically, the developed module can be used as an innovative and measurable training alternative for coaches. However, this study is limited by a relatively small sample size and a short intervention duration. Therefore, future research is recommended to involve larger samples, longer intervention periods, and more rigorous research designs to enhance the validity of the findings.

Acknowledgement

The authors would like to express their sincere gratitude to all individuals and institutions who contributed to the completion of this study. Special appreciation is extended to the supervisors for their valuable guidance, constructive feedback, and continuous support throughout the research process. The authors also acknowledge the athletes and coaching staff of PB ALTREC for their active participation and cooperation during the data collection phase. In addition, appreciation is given to all parties who provided technical, administrative, and moral support in the implementation of this research.

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