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Development and preliminary validation of an electronic reaction training device for assessing Dwi Chagi reaction time and kick accuracy

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ABSTRACT

Background: Successful execution of the Dwi Chagi kick requires rapid reaction time and precise kick placement. Although various training interventions have been developed to improve kicking performance, objective assessment during routine training remains limited because evaluations are still largely based on conventional coach observation. **Objectives:** This study aims to develop and evaluate an electronic reaction training device for objectively assessing reaction time and Dwi Chagi kick accuracy in junior taekwondo athletes. **Methods:** This study employed a modified three-stage Research and Development model consisting of the Define, Design, and Develop phases. The device was designed, prototyped, and evaluated through expert validation involving three nationally certified taekwondo coaches and three sports instrumentation experts. Content validity was assessed using Aiken's V coefficient, whereas operational performance was evaluated through field testing involving 16 junior taekwondo athletes. Measurement reliability was examined using inter-rater and test–retest Intraclass Correlation Coefficients (ICC). **Results:** The developed device demonstrated excellent content validity (Aiken's V = 0.889) and good-to-excellent measurement reliability (ICC = 0.86-0.91). Field evaluation demonstrated that the system successfully generated randomised visual stimuli, objectively recorded reaction time, and automatically assessed Dwi Chagi kick accuracy, achieving successful detection rates of 82.0% for left-leg kicks and 88.0% for right-leg kicks. **Conclusion:** The proposed electronic reaction training device demonstrated satisfactory content validity, operational feasibility, and measurement reliability, indicating its potential as a practical tool for objective reaction-time and kick-accuracy assessment during taekwondo training. However, further criterion validation against established reference systems is required before widespread implementation.

Keywords: Dwi chagi; electronic reaction device; reaction time; sports technology; taekwondo

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INTRODUCTION

Taekwondo is an Olympic combat sport characterised by dynamic kicking techniques that require high levels of speed, precision, coordination, and tactical decision-making (Hidayat et al., 2026; Menescardi, Estevan et al., 2021). Successful performance in taekwondo depends not only on technical proficiency but also on the athlete's ability to execute rapid and accurate movements in response to unpredictable competitive situations (Fachrezzy et al., 2024; Zhang et al., 2025). Previous studies have consistently demonstrated that physical fitness components, including muscular strength, explosive power, reaction speed, coordination, and neuromuscular control, play critical roles in determining competitive performance among taekwondo athletes athletes (Liu & He, 2022; Scamardella et al., 2025).

Among the various kicking techniques performed in kyorugi, the Dwi Chagi (back kick) is recognised as one of the most effective scoring techniques because it generates substantial impact force while allowing athletes to rapidly transition between offensive and defensive actions (Sousa et al., 2024). Successful execution of this technique requires the coordinated integration of lower-limb strength, balance, flexibility, body coordination, reaction speed, and kicking accuracy (Ariansyah et al., 2017). Consequently, accurate assessment of both reaction time and kick accuracy is essential for monitoring technical performance, identifying athletes' strengths and weaknesses, and optimising training programmes.

To improve Dwi Chagi performance, various training interventions have been proposed. Elastic resistance training has been reported to enhance kicking velocity and lower-limb performance (Paulauskas et al., 2025), whereas plyometric training improves explosive power and kicking speed in taekwondo athletes (Zulkarnain et al., 2021). Although these interventions have demonstrated positive effects on kicking performance and physical capacity, their effectiveness has generally been evaluated using conventional outcome measures, such as kick velocity or physical fitness tests. As a result, limited attention has been given to objectively measuring the reaction process and kicking accuracy during actual skill execution.

Recent advances in sports technology have enabled the development of electronic assessment systems for combat sports. Wearable inertial sensors have been applied in karate, taekwondo, and mixed martial arts to quantify movement speed, coordination, and biomechanical performance performance (Xue et al., 2025), while smart boxing gloves have demonstrated high accuracy in recognising punching techniques and target locations during training (Worsey et al., 2019). Likewise, electronic body protectors and electronic helmets have been developed primarily to improve scoring accuracy, impact detection, and fairness during taekwondo competitions (Apollaro & Falcó, 2021; Ki et al., 2019; Márquez et al., 2022; Qureshi & Krishnan, 2022). These technologies have substantially improved objective performance assessment, particularly in competitive environments.

Despite these technological advances, important limitations remain. Commercial electronic protector systems, such as Daedo and KP&P, were primarily developed to improve scoring accuracy, impact detection, and officiating during official taekwondo competitions rather than to support reaction-based technical training (Apollaro & Falcó, 2021; Razman & Chong, 2019; Sevinç & Çolak, 2019). Likewise, wearable inertial measurement unit (IMU) systems are effective for monitoring biomechanical variables and movement kinematics but generally require body-mounted sensors and provide limited real-time feedback for routine coaching (Picerno et al., 2021; Xue et al., 2025). Motion-capture systems remain the gold standard for biomechanical analysis; however, they require specialised laboratory facilities, multiple high-speed cameras, and complex data processing, making them impractical for everyday taekwondo training (Çıklaçandır et al., 2024; Kim et al., 2017). Consequently, coaches continue to rely on either competition-oriented technologies or laboratory-based biomechanical systems that provide limited support for simultaneous reaction-based training and objective kick-accuracy assessment.

To the best of our knowledge, no previous study has developed an electronic reaction training device that simultaneously integrates programmable reaction stimulus generation, automatic reaction-time measurement, and target-based Dwi Chagi kick-accuracy assessment within a single portable training platform. Unlike Daedo and KPnP electronic protector systems designed for competition scoring, wearable IMU systems intended for biomechanical monitoring, smart protectors developed primarily for impact detection, or laboratory-based motion-capture systems, the proposed device was specifically designed for routine training by providing real-time reaction stimuli together with objective assessment of both reaction time and kick accuracy. This integrated approach enables coaches to conduct evidence-based reaction training using a practical, portable, and cost-effective system suitable for daily training environments. Therefore, this study aims to (i) develop an electronic reaction training device for Dwi Chagi kick practice, (ii) evaluate its content validity and measurement reliability, and (iii) examine its operational performance and feasibility for objectively assessing reaction time and Dwi Chagi kick accuracy in junior taekwondo athletes.

METHODS

Research Design

This study employed a Research and Development (R&D) design to develop and validate an electronic reaction training device for objectively assessing reaction time and Dwi Chagi kick accuracy in junior taekwondo athletes. The development process followed a modified three-stage (3D) framework consisting of the Define, Design, and Develop phases, adapted from the original Four-D (4D) model by omitting the Disseminate stage. This modification is appropriate for prototype-oriented studies focusing on product development, expert validation, and preliminary field evaluation before large-scale implementation (Dahlan et al., 2025; Irawan et al., 2024). Following prototype development, the device underwent content validation, field performance evaluation, and measurement reliability testing.

Participants

Two groups of participants were involved in this study. The first group consisted of six expert validators, including three nationally certified taekwondo coaches and three university-based sports instrumentation experts. These experts evaluated the prototype regarding hardware design, software functionality, sensor responsiveness, operational feasibility, safety, and innovation. The second group comprised 16 junior taekwondo athletes (age = 17.10 ± 0.87 years; body mass = 57.30 ± 4.80 kg; height = 168.20 ± 5.60 cm; training experience = 3.40 ± 1.17 years), who participated in the field performance evaluation and test–retest reliability assessment. Participants were recruited using purposive sampling.

The sample size was considered appropriate for this preliminary prototype evaluation because the primary objective was to assess the operational performance and measurement reliability of the developed device rather than to estimate population parameters or compare intervention effects. Previous methodological studies have suggested that sample sizes ranging from 15 to 30 participants are generally adequate for preliminary reliability studies and instrument development when repeated measurements are obtained under standardised conditions (Koo & Li, 2016). The inclusion criteria were: (i) active junior taekwondo athletes, (ii) a minimum of three years of regular taekwondo training, (iii) free from musculoskeletal injury during testing, and (iv) willingness to participate voluntarily. Athletes with injuries or medical conditions that could interfere with maximal kicking performance were excluded.

Table 1. Characteristics of Junior Taekwondo Athletes

Variable	Mean ± SD
Age (years)	17.10 ± 0.87
Height (cm)	168.20 ± 5.60
Body Mass (kg)	57.30 ± 4.80
Training Experience (years)	3.40 ± 1.17

Electronic Reaction Training Device

The developed electronic reaction training device consisted of a modified taekwondo body protector (81.5 × 40 × 26.5 cm) equipped with 80 capacitive push-button sensors distributed across three predefined target zones to detect Dwi Chagi kick impacts. The system was controlled using an Arduino Uno microcontroller, which coordinated stimulus generation, sensor activation, and real-time data acquisition. Randomised visual stimuli were generated using programmable light-emitting diodes (LEDs) to minimise anticipation bias. Upon successful contact with the activated target, the system automatically recorded reaction time, identified the corresponding target zone, calculated the accuracy score, and stored performance data for subsequent analysis.

An integrated LCD displayed reaction time and kick accuracy immediately after each trial. Dedicated software processed all sensor inputs, classified kick accuracy, and stored measurement data automatically.

Before field implementation, all sensors were calibrated to ensure consistent activation across the three target zones. Sensor calibration was performed by repeatedly applying standardised impacts to each sensor until uniform activation responses were achieved. The capacitive push-button sensors were configured with identical activation thresholds to minimise variations in sensor sensitivity between target areas. Sensor response was processed in real time through the Arduino Uno microcontroller, allowing reaction time to be recorded immediately after activation of the visual stimulus and successful target contact. Prior to data collection, repeated functional testing confirmed stable communication between the sensors, microcontroller, LED stimulus system, and data acquisition software throughout the testing procedures.

Content Validity

Content validity was evaluated by six expert validators using a structured evaluation instrument consisting of six assessment domains: hardware design, software functionality, sensor accuracy, operational feasibility, safety, and innovation. Each domain was rated using a four-point Likert scale ranging from 1 (not relevant) to 4 (highly relevant). The level of agreement among experts regarding the relevance of each evaluation criterion was quantified using Aiken's V coefficient, with values ≥ 0.70 considered acceptable for content validity. Components that did not meet the recommended threshold were revised before proceeding to the field evaluation stage.

Field Performance Evaluation

Following expert validation, the operational performance of the developed device was evaluated through field testing involving sixteen junior taekwondo athletes. Each participant performed repeated Dwi Chagi kicks in response to randomised visual stimuli automatically generated by the electronic system under standardised testing conditions. During each trial, the device automatically generated visual reaction stimuli, detected kick impacts, recorded reaction time from stimulus onset to target contact, identified the activated target zone, calculated kick accuracy, and stored all performance data. Field evaluation was conducted to examine the operational functionality and practical performance of the developed system in objectively assessing reaction time and Dwi Chagi kick accuracy during taekwondo training.

For prototype evaluation purposes, kick accuracy was quantified using a predefined three-zone scoring system developed specifically for this study based on expert recommendations. The central target zone was assigned 10 points, the middle zone 5 points, and the outer zone 1 point to represent high-, moderate-, and low-accuracy kick placement, respectively. This scoring system was designed to differentiate kick placement during training and provide quantitative feedback on kicking accuracy; it was not intended to replicate the official World Taekwondo competition scoring system.

Reliability Testing

Inter-rater Reliability

Inter-rater reliability was evaluated using ratings provided independently by the six expert validators. The consistency of expert evaluations across the six assessment domains was analysed using the Intraclass Correlation Coefficient (ICC) based on a two-way random-effects model with absolute agreement (ICC [2,1]), which is appropriate when both raters and ratings are considered representative of a larger population and the objective is to assess absolute agreement among independent evaluators (Koo & Li, 2016).

Test-Retest Reliability

Test–retest reliability was assessed using the same group of sixteen junior taekwondo athletes. Participants completed identical testing procedures on two separate occasions under standardised conditions with a seven-day interval between testing sessions. Reaction time and kick accuracy obtained from both sessions were analysed using the Intraclass Correlation Coefficient based on a two-way random-effects model with absolute agreement (ICC [2,1]) to determine measurement stability over time. ICC values were interpreted according to commonly accepted criteria as poor (< 0.50), moderate (0.50-0.75), good (0.75-0.90), and excellent (> 0.90) (Koo & Li, 2016).

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA). Content validity was evaluated using Aiken's V coefficient, with values ≥ 0.70 indicating acceptable agreement among expert validators. Inter-rater reliability and test–retest reliability were analysed using the Intraclass Correlation Coefficient (ICC) based on a two-way random-effects model with absolute agreement. ICC values were interpreted as poor (< 0.50), moderate (0.50-0.75), good (0.75-0.90), and excellent (> 0.90). Descriptive statistics, including the mean and standard deviation (Mean ± SD), minimum and maximum values, successful detection rates, and target-zone distributions, were calculated to summarise reaction time and Dwi Chagi kick accuracy obtained during the field performance evaluation.

Because the primary objective of this study was prototype development and preliminary evaluation of the device's operational performance and measurement reliability, field-testing data were analysed descriptively rather than inferentially. Descriptive statistics were considered appropriate to summarise the device's ability to record reaction time, detect kick accuracy, and demonstrate operational functionality during standardised testing, without the intention of comparing athletes' performance between kicking sides or making population-level inferences.

Ethical Considerations

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Ethical approval was obtained from the Institutional Research Ethics Committee of Universitas Negeri Jakarta, Indonesia (Approval No.589/UN39.14/PT.01.02/2026). Written informed consent was obtained from all participants before data collection. For participants younger than 18 years of age, written informed consent was additionally obtained from their parents or legal guardians. Participants were informed of the study objectives, procedures, potential risks, and their right to withdraw from the study at any time without consequence. All data were anonymised, treated confidentially, and used exclusively for research purposes.

RESULTS AND DISCUSSION

Results

Prototype Development

The development process resulted in an operational electronic reaction training device designed to objectively assess reaction time and Dwi Chagi kick accuracy in junior taekwondo athletes. The finalised prototype (**Figure 1**) consists of a modified taekwondo body protector equipped with 80 capacitive push-button sensors, an Arduino Uno microcontroller, programmable LED indicators for randomised visual stimulus generation, an LCD interface for real-time feedback, and dedicated software for automatic data processing. The operational workflow of the system is illustrated in **Figure 2**. Each assessment begins when the athlete activates the foot switch, triggering the Arduino-based controller to generate a randomised visual stimulus. The athlete then performs a Dwi Chagi kick toward the illuminated target, after which the system automatically detects the impact, records reaction time, determines kick accuracy, and displays the results in real time. Operational testing confirmed that all hardware and software components functioned reliably throughout repeated testing without sensor malfunction or communication failure. These findings demonstrate the operational feasibility and practical applicability of the developed prototype for objective reaction-based taekwondo training.

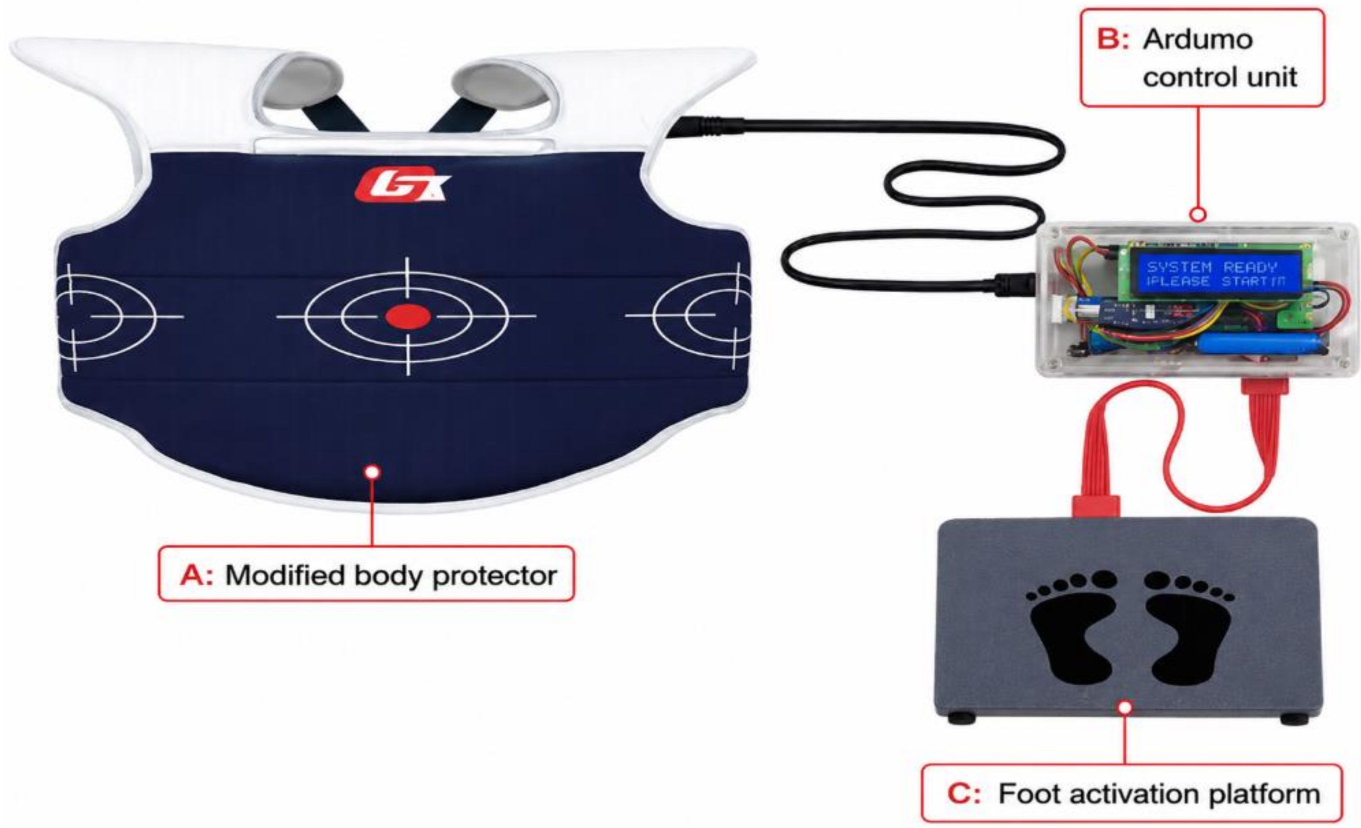

Figure 1. Components of the Developed Electronic Reaction Training Device: (A) Modified Body Protector with Target Zones; (B) Arduino-Based Control Unit with LCD Display; (C) Foot Activation Platform Used to Initiate Reaction Trials

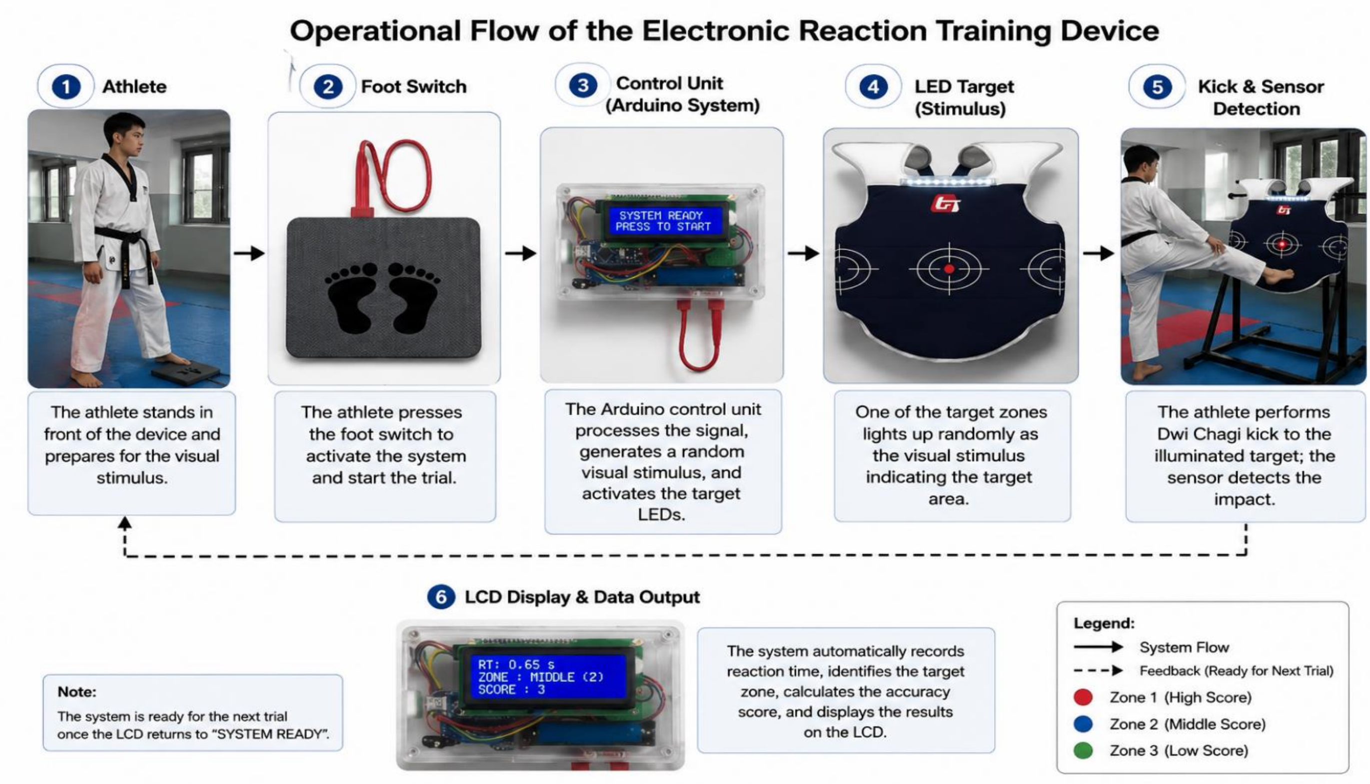

Figure 2. Operational Workflow of the Electronic Reaction Training Device for Dwi Chagi Kick Assessment

Content Validity

Content validity was evaluated by six expert validators, comprising three nationally certified taekwondo coaches and three sports instrumentation specialists. The experts assessed six aspects of the developed device, including hardware design, software functionality, sensor accuracy, operational feasibility, safety, and innovation. The level of agreement among experts was quantified using Aiken’s V coefficient.

Table 2. Content Validity Results of the Electronic Reaction Training Device

Aspect	Aiken's V	Interpretation
Hardware Design	0.93	Excellent
Software Functionality	0.93	Excellent
Sensor Accuracy	0.87	Good
Operational Feasibility	0.87	Good
Safety	0.93	Excellent
Novelty	0.93	Excellent
Overall Mean	**0.91**	**Excellent**

As presented in **Table 2**, the Aiken's V coefficients ranged from 0.87 to 0.93, with an overall mean of 0.91, indicating excellent content validity. The highest agreement among experts was obtained for hardware design, software functionality, safety, and innovation (V = 0.93). Sensor accuracy and operational feasibility also demonstrated good validity (V = 0.87), exceeding the recommended acceptance threshold of 0.70. These findings indicate that the developed device possesses adequate content validity and is appropriate for subsequent field evaluation.

Field Performance Evaluation

Following expert validation, the prototype was evaluated by sixteen junior taekwondo athletes to examine its operational performance during Dwi Chagi execution. During field testing, the device successfully generated randomised visual stimuli, automatically detected kick impacts, recorded reaction time, and classified kick accuracy according to the predefined scoring zones across all testing sessions. These findings demonstrate that the developed system functioned as intended under practical training conditions and was capable of objectively measuring reaction time and kick accuracy during Dwi Chagi performance.

Reaction Time Performance

Reaction time was automatically recorded from the onset of the visual stimulus until the activated sensor detected a valid Dwi Chagi kick.

Table 3. Descriptive Statistics of Dwi Chagi Reaction Time

Variable	n	Mean ± SD (s)	Minimum	Maximum	Valid Detection Rate (%)
Left Dwi Chagi	16	0.71 ± 0.07	0.60	0.84	82.0%
Right Dwi Chagi	16	0.65 ± 0.05	0.57	0.74	88.0%

Note. Valid detection rate represents the percentage of kicks correctly detected by the activated target sensor during field testing.

As presented in **Table 3**, the developed device consistently recorded reaction time throughout the field evaluation. Descriptively, the mean reaction time recorded for the right-leg Dwi Chagi (0.65 ± 0.05 s) was lower than that recorded for the left-leg Dwi Chagi (0.71 ± 0.07 s). The corresponding valid detection rates were 88.0% and 82.0% for the right and left legs, respectively, indicating that the system successfully detected most kicking responses under randomised visual stimulus conditions. Because the primary purpose of the field evaluation was to assess the operational performance of the developed device rather than to compare athletes’ performance between kicking sides, no inferential statistical analyses were conducted. Therefore, these findings should be interpreted as descriptive indicators of the device’s operational capability. The factors contributing to unsuccessful detections were not specifically examined in the present study; therefore, whether these events were associated with athlete execution, sensor performance, or other technical factors remains to be investigated.

Kick Accuracy Performance

The developed system automatically identified the target zone contacted by each kick and assigned scores according to the predefined scoring criteria.

Table 4. Distribution of Dwi Chagi Kick Accuracy

Target Zone	Successful Hits	Percentage (%)	Score
Zone 1 (Center – 10 points)	18	45.0	180
Zone 2 (Middle – 5 points)	16	40.0	80
Zone 3 (Outer – 1 point)	6	15.0	6
Total	**40**	**100.0**	**266**

Note. Scores were calculated using the predefined three-zone scoring system developed for prototype evaluation, in which Zone 1, Zone 2, and Zone 3 represented high-, moderate-, and low-accuracy kick placement, respectively. This scoring system was developed for training evaluation and does not represent the official World Taekwondo competition scoring system.

As presented in **Table 4**, nearly half of all successful kicks (45.0%) were detected in Zone 1, corresponding to the highest accuracy category. Zone 2 accounted for 40.0% of successful kicks, whereas Zone 3 represented 15.0%. Based on the predefined scoring system, the accumulated score reached 266 points, indicating that the developed device successfully differentiated kick placement across the three target zones and objectively quantified kicking accuracy during Dwi Chagi performance.

Reliability

Inter-Rater Reliability

The consistency of expert evaluations regarding the developed device was assessed using the Intraclass Correlation Coefficient (ICC).

Table 5. Inter-Rater Reliability of Expert Evaluation

Assessment Aspect	ICC	95% CI	Interpretation
Overall expert evaluation	0.91	0.84-0.96	Excellent

As shown in **Table 5**, the inter-rater reliability analysis yielded an ICC of 0.91, indicating excellent agreement among expert validators. This finding demonstrates that the evaluation criteria were consistently interpreted across experts, supporting the reliability of the expert validation process.

Test–Retest Reliability

Measurement stability was further evaluated through repeated testing involving the junior taekwondo athletes.

Table 6. Test–Retest Reliability of the Electronic Reaction Training Device

Variable	ICC	95% CI	Interpretation
Left reaction	0.86	0.72–0.93	Good
Right reaction	0.91	0.81–0.96	Excellent
Kick accuracy	0.88	0.75–0.94	Good
Overall	0.89	0.77–0.95	Good

As presented in **Table 6**, the developed electronic reaction training device demonstrated good-to-excellent measurement stability across repeated testing sessions. The highest reliability was observed for right-leg reaction time (ICC = 0.91), followed by kick accuracy (ICC = 0.88) and left-leg reaction time (ICC = 0.86). The overall ICC value of 0.89 indicates that the developed device provides stable, consistent, and reproducible measurements of both reaction time and Dwi Chagi kick accuracy.

Collectively, these findings demonstrate that the developed electronic reaction training device possesses excellent content validity, satisfactory operational performance, and good-to-excellent measurement reliability. The prototype consistently generated randomised visual stimuli, objectively recorded reaction time, automatically classified kick accuracy, and produced stable measurements across repeated testing, supporting its feasibility as an objective assessment tool for reaction-based taekwondo training.

Discussion

The present study developed and evaluated an electronic reaction training device designed to objectively assess reaction time and Dwi Chagi kick accuracy in junior taekwondo athletes. The prototype operated successfully throughout the field evaluation, demonstrating adequate operational feasibility under standardised training conditions. The findings further revealed excellent content validity, good-to-excellent measurement reliability, and satisfactory field performance. Collectively, these findings indicate that the developed system provides valid, reliable, and objective measurements of reaction-based kicking performance, supporting its application as a practical assessment tool for evidence-based taekwondo training.

The excellent content validity obtained in this study reflects a high level of agreement among taekwondo experts and sports instrumentation specialists regarding the appropriateness of the hardware design, software functionality, sensor accuracy, operational feasibility, safety, and innovation of the developed device. All evaluated components exceeded the recommended Aiken's V threshold, indicating that the evaluation criteria adequately represented the intended measurement constructs of the developed device. These findings are consistent with previous studies demonstrating that Aiken's V provides robust evidence of expert agreement during the development and validation of sports measurement instruments (Pérez-Rivas et al., 2023; Feligreras-Alcalá et al., 2021; Guhabiswas et al., 2021). Furthermore, multidisciplinary expert evaluation has been recognised as an essential step in developing electronic sports technologies to ensure technical feasibility, measurement accuracy, safety, and practical usability before field implementation (Worsey et al., 2019; Jia et al., 2023).

The field performance evaluation demonstrated that the developed device successfully generated randomised visual stimuli, automatically detected kick impacts, objectively recorded reaction time, and classified kick accuracy throughout all testing sessions. These findings demonstrate that the developed prototype functioned reliably under practical training conditions throughout the field evaluation. The successful detection rates of 82.0% for left-leg kicks and 88.0% for right-leg kicks further demonstrate the system's ability to consistently recognise valid kicking responses during randomised reaction tasks. Descriptively, shorter reaction times were observed for right-leg Dwi Chagi than for left-leg Dwi Chagi. This pattern may reflect dominant-limb specialisation and greater neuromuscular efficiency. However, because no inferential statistical comparison between limbs was performed, this interpretation should be considered preliminary. This descriptive approach was adopted because the primary objective of this study is to evaluate the operational performance of the developed device rather than to compare athletes' performance between kicking sides. Previous studies have reported that reaction performance in combat sports is influenced by perceptual processing, neuromuscular coordination, motor control, and technical proficiency (Fachrezzy et al., 2024; Menescardi, Estevan et al., 2021). Moreover, highly skilled athletes generally demonstrate faster stimulus recognition and motor responses than less experienced performers, allowing more effective execution of offensive and defensive techniques under severe time constraints (Ervilha et al., 2020; Rodrigues et al., 2025; Bridge et al., 2014).

An important advantage of the developed system is the use of randomised visual stimuli combined with automatic reaction-time recording. Unlike conventional coach-based observation, which is susceptible to subjective judgment and human reaction error, the proposed electronic system provides objective, automated, and real-time measurements of athletes' responses. Randomised stimulus presentation also minimises anticipation bias during repeated training sessions, thereby providing a more ecologically valid assessment of perceptual-motor performance. This approach more closely resembles the unpredictable stimulus conditions encountered during competitive taekwondo performance. In addition, the immediate feedback displayed through the integrated LCD enables coaches and athletes to monitor performance instantly, facilitating evidence-based training adjustments and individualised coaching decisions.

Another important finding concerns the device's capability to objectively evaluate Dwi Chagi kick accuracy using predefined target zones. The distribution of successful kicks across the three target zones demonstrates the ability of the proposed system to objectively differentiate kick placement according to the programmed scoring algorithm. Accurate kick placement is a critical determinant of competitive success because scoring in taekwondo depends not only on impact force but also on striking the intended scoring area with appropriate timing and precision (Ko et al., 2021; Xu et al., 2025). Previous studies have demonstrated that kicking accuracy is strongly influenced by neuromuscular coordination, postural stability, movement control, and lower-limb biomechanics (Menescardi, Falcó et al., 2021). Furthermore, target-based electronic assessment has become increasingly important for providing objective performance feedback and supporting technical skill refinement during athlete development (Cho et al., 2020; Jaén-Carrillo et al., 2024; Park et al., 2021). Therefore, the present findings indicate that the developed device can provide coaches with objective information regarding both reaction efficiency and kick placement during routine taekwondo training.

The reliability analysis further strengthens the practical value of the proposed device. The good-to-excellent ICC values indicate that reaction time and kick accuracy measurements remained stable across repeated testing sessions, demonstrating that the system produced consistent and reproducible measurements. High measurement reliability is essential in sports performance evaluation because coaches require dependable data to monitor athlete development, evaluate training effectiveness, and identify meaningful performance changes over time. Similar findings have been reported for wearable sensing systems and electronic assessment technologies developed for combat sports, where measurement consistency is considered fundamental for evidence-based athlete monitoring (Apollaro & Falcó, 2021; Liu et al., 2024). Consequently, the high reliability observed in the present study supports the application of the developed device as a practical monitoring tool during routine taekwondo practice.

From a practical perspective, the developed electronic reaction training device provides coaches with an objective and efficient alternative to conventional observation-based assessment. By integrating randomised visual stimuli, automatic reaction-time measurement, target-based kick accuracy assessment, and real-time performance feedback within a portable system, the device enables immediate evaluation of athletes' performance during routine training sessions. This capability may facilitate evidence-based coaching, individualised training adjustments, and continuous monitoring of athletes' perceptual-motor performance without requiring expensive motion-analysis laboratories or highly specialised biomechanical instrumentation.

A major contribution of the present study lies in integrating multiple assessment functions within a single portable training system. Previous electronic technologies in taekwondo have primarily been developed to improve scoring accuracy during official competitions or to monitor biomechanical variables using wearable sensors (Apollaro & Falcó, 2021; Márquez et al., 2022). In contrast, the proposed device was specifically designed for training environments by integrating randomised reaction stimuli, automatic reaction-time measurement, target-zone detection, kick-accuracy assessment, and real-time performance feedback into a unified platform. This integrated approach enables coaches to simultaneously evaluate athletes' perceptual-motor responses and technical execution while providing immediate objective feedback that supports individualised, data-driven training. Accordingly, the proposed system fills an important gap between competition-orientated electronic scoring systems and practical training-orientated performance assessment tools.

Although the developed device demonstrated satisfactory content validity, operational performance, and measurement reliability, these findings should be interpreted within the scope of this preliminary validation study. The present investigation established evidence of content validity and measurement consistency but did not evaluate criterion validity against established reference systems. Therefore, although the device appears feasible and reliable for objective reaction-time and kick-accuracy assessment during training, its measurement accuracy relative to gold-standard biomechanical instruments remains to be established.

Several limitations should be acknowledged. First, the prototype was evaluated using a relatively small sample consisting exclusively of junior taekwondo athletes. Although adequate for this preliminary reliability study, larger and more diverse samples are required to improve the precision and generalisability of the findings. Second, the developed system was evaluated only for the Dwi Chagi technique and therefore cannot yet be generalised to other taekwondo kicking techniques. Third, although the device demonstrated excellent content validity, satisfactory operational performance, and high measurement reliability, criterion validity was not established because its measurements were not compared with recognised reference systems such as motion-capture systems, high-speed video analysis, official electronic body protectors, or electronic timing systems. Consequently, the findings demonstrate measurement consistency rather than confirmed measurement accuracy. Finally, the device was evaluated only under controlled indoor training conditions. Future studies should establish criterion validity against gold-standard measurement systems, evaluate additional taekwondo techniques, involve larger athlete populations, and examine the device across different training environments.

CONCLUSION

This study successfully developed an electronic reaction training device for assessing reaction time and Dwi Chagi kick accuracy in junior taekwondo athletes. The findings demonstrated excellent content validity, satisfactory field performance, and good-to-excellent measurement reliability, supporting the feasibility of the proposed device as a practical tool for objectively assessing reaction time and kick accuracy during taekwondo training. Unlike conventional observation-based assessment and electronic systems primarily designed for competition scoring, the developed device integrates randomized visual stimuli, automatic reaction-time measurement, target-based kick accuracy assessment, and real-time performance feedback within a single training platform. These features provide coaches and practitioners with an objective and standardised approach for monitoring athletes' performance during routine training. However, because criterion validity was not established, further validation against gold-standard biomechanical reference systems is required before the device can be recommended for widespread research and professional application. Future studies should therefore establish criterion validity by comparing the proposed device with motion-capture systems, high-speed video analysis, official electronic body protectors, or electronic timing systems, while also evaluating larger and more diverse athlete populations and extending the application of the device to additional taekwondo kicking techniques.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AI DISCLOSURE STATEMENT

The authors used QuillBot solely for language editing, grammar checking, and improving the readability of the manuscript. No generative artificial intelligence (AI) tools were used to generate, analyse, interpret, summarise, or write the scientific content of this manuscript. All scientific concepts, study design, data collection, data analysis, interpretation of results, and conclusions were developed exclusively by the authors, who take full responsibility for the originality, accuracy, and integrity of the work.

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