REFLX: Reaction Enhancement in Fitness using Light-based Exercises for UPV Athletes

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Abstract

Traditional training methods, such as cone and ladder drills, inadequately simulate the rapid, stimulus-driven demands of real-game scenarios in racket sports like badminton, tennis, and table tennis. While commercial light-based systems like FITLIGHT and BlazePod show promise in enhancing visual-motor coordination, reaction speed, and agility, they are hindered by high costs, connectivity issues, and limited transferability from lab to field performance. This research proposes an integrated hardware–software solution utilizing infrared sensors, RGB LED modules, and audio cues to deliver multimodal stimuli capable of simulating sport-specific decision-making demands. The study outlines the design, construction, and calibration of a wireless IoT-enabled prototype employing ESP-NOW communication for real-time responsiveness and synchronized data capture.

Experimental trials will evaluate the system's effectiveness in improving reaction time and agility compared with traditional methods, while usability assessments will gather insights from athletes and coaches to refine functionality and user experience. By merging principles from computer science, sports science, and human–computer interaction, this study contributes to the development of accessible, evidence-based athletic training technologies and provides a foundation for future enhancements in adaptive, data-driven performance systems.

Keywords: Wireless integrated network sensors, sensor networks, applied computing, human-centered computing, interactive systems and tools

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Chapter 1

Introduction

1.1 Overview of the Current State of Technology

In the realm of sports science, the enhancement of athletes' response time and agility remains a critical focus, as these attributes directly influence performance in dynamic, unpredictable environments such as team sports and combat disciplines (Hassan, Alibrahim, & Sayed Ahmed, 2023). Traditional training methods, including cone drills and ladder exercises, have long been employed to improve these skills, yet they often fall short in replicating the rapid, stimulus-driven demands of real-game scenarios. Over the past decade, light-based reaction training systems—devices utilizing visual stimuli like LED lights to prompt immediate motor responses—have emerged as innovative tools to bridge this gap. Systems such as FITLIGHT, BlazePod, and XLiGHT have been critically analyzed for their design features, including sensor connectivity, battery life, and operational reliability, revealing strengths in portability and customization but limitations in diagnostic precision and validity (Ezhov, Zakharova, & Kachalov, 2021).

Empirical studies have demonstrated that these systems can significantly enhance visual-motor coordination, reaction speed, and cognitive functions. For instance, interventions using FITLIGHT in small-sided games have led to marked improvements in harmonic abilities (e.g., rhythmization and responsiveness) and basic skills like dribbling among young basketball players (Hassan et al., 2023). Similarly, a 10-week FITLIGHT program improved reaction times and dribbling speeds in female basketball athletes, with effect sizes indicating substantial neural adaptations (Hassan, 2025). In motorsport contexts, light-based reactive agility training has boosted selective attention, cognitive flexibility, and cardiorespiratory capacity in car racing drivers (Horváth et al., 2022). A systematic review of visual training interventions, including light board and stroboscopic methods, further corroborates these benefits, reporting 5-27% reductions in reaction time across various sports, with greater efficacy in elite and younger athletes (Jothi et al., 2025). Reliability assessments of systems like BlazePod have also affirmed their validity for measuring simple and complex reactions in mixed martial arts (MMA) athletes, with high intraclass correlations supporting their use in training protocols (Polechoński, Pilch, Prończuk, Markowski, & Maszczyk, 2024).

Despite these advancements, significant gaps persist in the literature. While light-based systems show promise in controlled settings, their predictive value for field-based reactive agility remains limited, as evidenced by weak correlations between laboratory reaction speeds and on-field performance in soccer players (Broodryk, Skala, & Broodryk, 2025). This suggests a disconnect between isolated visual stimuli and the multifaceted perceptual-cognitive demands of sports, highlighting the need for more integrated, sport-specific designs. Moreover, comparative analyses underscore inconsistencies in system performance, such as variable Bluetooth stability and sensor delays, which could undermine training reproducibility (Ezhov et al., 2021). Long-term efficacy studies are scarce, and few investigations explore the interdisciplinary integrations between sports science and engineering to optimize these technologies.

1.2 Problem Statement

While traditional methods such as cone and ladder drills have been widely used to enhance reaction time and agility, they often fail to simulate the complex, stimulus-driven conditions of real-game scenarios (Hassan et al., 2023). Recent light-based reaction training systems have shown potential in improving visual-motor coordination and cognitive response (Horváth et al., 2022; Jothi et al., 2025). However, these systems remain limited by high costs, connectivity issues, and questionable transferability of laboratory-based improvements to on-field performance (Broodryk et al., 2025; Ezhov et al., 2021).

If these limitations persist, athletes may continue to rely on training tools that inadequately reflect actual gameplay conditions, hindering optimal skill development and competitive performance. Addressing these gaps necessitates the development of a customizable, low-cost, and scientifically validated light-based reaction training system that bridges engineering innovation and applied sports performance research, which our study aims to do as well as evaluate the effectiveness of said system.

1.3 Research Objectives

1.3.1 General Objective

The goal of this study is to develop and evaluate a light-based reaction training system that enhances the response time and agility of athletes, specifically in racket sports such as badminton, tennis, and table tennis.

1.3.2 Specific Objectives

Specifically, this study aims to:

1. design and construct a device equipped with infrared sensors, RGB lights, and speakers for accurate motion detection and response measurement, as well as better user experience,
2. develop a software application that manages the device operations, records performance data, and functions both online and offline,
3. calibrate and test the system to ensure precision, responsiveness, and synchronization between hardware and software components.
4. conduct experimental trials assessing the system's effectiveness in improving athletes' response time and agility compared to traditional training methods, and
5. evaluate the system's usability, functionality, and overall user satisfaction based on feedback from athletes and coaches.

1.4 Scope and Limitations of the Research

This study focuses on the design, development, and short-term evaluation of a programmable light-based reaction training system specifically tailored for racket sports, including badminton, tennis, and table tennis. These sports were selected because they demand rapid visual processing, anticipatory decision-making, and fine motor control—abilities strongly linked to reaction time and agility.

Experimental trials will be conducted in controlled indoor training environments, using drills that simulate racket-sport scenarios such as serve returns, directional changes, and split-step reactions. The prototype system will incorporate LED visual cues and integrated speakers to deliver multimodal stimuli, allowing assessment of both single and dual sensory response conditions.

The evaluation will be limited to short-term performance outcomes, measuring pre-post changes in reaction and movement response metrics following exposure to the prototype system. Long-term effects, such as learning retention, in-game transfer, or perceptual-cognitive adaptations, are beyond the scope of this research.

1.5 Significance of the Research

This research integrates engineering, computer science, and sports science by developing a light- and sound-based reaction training system that enhances athletes' response time and agility through multimodal stimuli and data-driven feedback. Through a technical lens, the study contributes to the computer science community by implementing real-time sensor processing, audio-visual cue synchronization, and a user-centered software design. The inclusion of both infrared sensors and speakers allows for dynamic and varied training scenarios that engage multiple sensory pathways, thereby improving cognitive-motor coordination. Compared to existing systems that rely solely on visual cues or require expensive proprietary hardware, this design offers a more versatile, customizable, and cost-efficient solution.

From a societal perspective, the system democratizes access to advanced reaction training technologies by providing an affordable and portable tool suitable for athletes, coaches, and educational institutions. It can also serve as a supplementary device for rehabilitation programs that aim to improve motor control and sensory processing. By combining technical innovation with accessibility, this research promotes evidence-based athletic development and supports the broader integration of smart, adaptive technologies in sports and human performance training.

Chapter 2

Review of Related Literature

2.1 Physiological Basis of Reaction and Agility

Reaction time and agility in athletes are influenced by a complex interplay of neurophysiological factors, including perceptual-cognitive processing, neural pathways, and motor control. Reaction time encompasses the interval from stimulus detection to response initiation, modulated by sensory input (primarily visual), central nervous system processing, and efferent motor commands. Agility, defined as the ability to change direction rapidly while maintaining balance and speed, integrates these with biomechanical elements like strength and coordination (Pojskic et al., 2019). Neurophysiological mechanisms involve the visual cortex for stimulus detection, the prefrontal cortex for decision-making, and the basal ganglia for motor planning, with reaction accuracy linked to efficient attentional orienting and split attention across multiple stimuli (Chow, Kong, & Wong, 2022). The prefrontal studies highlight that perceptual factors, such as anticipation and visual search efficiency, contribute significantly, alongside physical attributes like explosive strength and elastic strength (Yildiz et al., 2020). For instance, factor analyses reveal independent components: explosive strength for acceleration, elastic strength for rebound, change-of-direction speed (CODS), and maximal strength. Correlations show that faster reaction times predict superior agility test performances, such as in the Illinois Agility Test or 20-m shuttle sprint, emphasizing the role of neural efficiency (Wang, Zhang, & Liu, 2024).

Methodologies in these studies often employ systematic reviews and correlational analyses, drawing from diverse athletic populations (e.g., team sports like soccer) (Turna, 2020). Limitations include reliance on lab-based tests that may not fully replicate field conditions, potentially underestimating contextual factors like fatigue or cognitive load (Pojskic et al., 2019). Implications suggest that training targeting neuroplasticity—through repeated stimuli—can enhance synaptic efficiency, reducing reaction latencies and improving agility in sports requiring rapid responses, such as basketball or racing (Chow et al., 2022). Patterns indicate stronger associations in high-level athletes, where cognitive fatigue and sleep quality positively correlate with prolonged reaction times, highlighting the need for holistic training approaches (Yildiz et al., 2020).

2.2 Existing Reaction Training Technologies

Commercial systems like FITLIGHT Trainer and BlazePod represent established light-based technologies for reaction training, with evidence supporting their effectiveness in enhancing athletic performance. FITLIGHT, a wireless LED sensor system, simulates game-like conditions to improve reaction time, reflexes, and cognitive functions (Hassan, 2025). Studies demonstrate its reliability, with testretest intraclass correlation coefficients (ICC) ranging from 0.81-0.90 and minimal detectable changes in reaction metrics (Steff, Badau, & Badau, 2024b). In young basketball players, a 10-week FITLIGHT intervention improved executive functions (e.g., inhibition, working memory) and fitness, though gains were comparable to traditional training, suggesting added cognitive demand without superior outcomes (Hassan, 2025). Another trial integrated FITLIGHT into small-sided games for 18 weeks, yielding significant enhancements in coordinative abilities and basic skills, outperforming controls with large effect sizes (Steff, Badau, & Badau, 2024a).

BlazePod, a pod-based visual-cognitive system, shows similar promise, with excellent reliability in balance activities (Çekok & Anaforoğlu, 2025). A 6-month program in adolescent soccer players improved simple reaction time and cognitive tasks, but between-group differences were non-significant compared to standard training, indicating contextual benefits rather than inherent superiority (Theofilou et al., 2022). Methodologies typically use randomized controlled trials (RCTs) with pre-post assessments, validated via tools like the Stroop Test for cognition and TUG for effort (Çekok & Anaforoğlu, 2025). Limitations include small samples (n = 20-50) and short durations (6-18 weeks), risking overestimation of effects due to novelty; discrepancies arise in massed vs. distributed scheduling, with longer protocols showing sustained gains (Steff et al., 2024a). Implications underscore these systems' role in individualized drills, boosting engagement through gamification, though high costs and proprietary designs limit accessibility for broader athletic populations (Hassan, 2025).

2.3 Light- and Sensor-Based Training Research

Research on light-based stimuli consistently shows enhancements in sports performance, particularly cognitive-motor integration and agility. A 6-week RCT using Witty SEM lights for car racing drivers improved cognitive abilities and cardiorespiratory fitness, with significant group-time interactions (Horváth et al., 2022). In basketball, light stimulation exercises enhanced attention focus (visual/auditory) and skilled hand speed, with pre-post improvements attributed to neuroplastic adaptations (Shimi, Kyriacou, & Avraamides, 2025). VR-adapted light tasks revealed attentional mechanisms, with orienting speed predicting performance, emphasizing split attention for larger stimuli arrays (Shimi et al., 2025). Soccer-specific lighting interventions (6 months) manipulated visual processing, reducing reaction times under varied conditions, though transfer to matches was inferred rather than directly measured (Theofilou et al., 2022).

Methodologies favor RCTs with tools like the Vienna Test System for cognition and breath-by-breath gas analysis for physiology, ensuring objective evidence (Horváth et al., 2022). Limitations encompass single-blinding, uncontrolled nutrition, and lab-based focus, potentially inflating effects; patterns show greater benefits in open-skill sports, with discrepancies in exercise vs. rest conditions (Zhao, Yang, Bo, Qi, & Zhu, 2024). Implications highlight light stimuli's potential for dual physical-cognitive gains, transferable to agility-dependent sports, but call for ecological validity in future studies (Shimi et al., 2025).

2.4 Identified Gaps in Literature

The literature reveals notable gaps, particularly the scarcity of open-source, customizable systems for individualized athlete training. While commercial tools like FITLIGHT dominate, they are proprietary and costly, limiting adaptation for diverse needs (Seçkin, Ateş, & Seçkin, 2023). Emerging technologies emphasize open-source platforms for tele-exercise, enabling collaborative customization via AI and IoT, yet only 9% of trials target healthy populations, with inadequate standardization of training parameters (Rebelo, Martinho, Valente-dos Santos, Coelho-e Silva, & Teixeira, 2023). Gaps include high dropout in asynchronous modes, data security concerns, and underexplored adherence factors (Rebelo et al., 2023). Methodologies in gap analyses rely on narrative reviews, highlighting sustainability challenges in open-source projects (Seçkin et al., 2023). This implicates the need for accessible systems to democratize training, addressing disparities in research on healthy athletes.

Chapter 3

Research Methodology

This study follows a step-by-step research process to develop and evaluate a light-based reaction training system for racket sports. The methodology includes gathering background information, consulting experts, and creating the initial system design. It then covers building the hardware prototype, developing the software, and testing the system with UPV athletes to measure reaction time and agility. Each stage is planned to ensure that the device is accurate, usable, and aligned with actual training needs. The process ends with analyzing the results and completing the final technical documentation.

3.1 Research Activities

Research activities include inquiry, survey, research, brainstorming, canvassing, consultation, review, interview, observe, experiment, design, test, document, etc.

3.1.1 Research and Consultation

In this phase, the researchers will work closely with the UPV PE department as they will serve as consultants to ensure and validate the feasibility of the proposed system for racket sports. This stage will involve a comprehensive research on reaction time and agility, focusing on light- and sound-based systems. The consultations will take place in the UPV Covered Court, specifically in the PE faculty rooms. This stage is important to establishing a strong theoretical foundation, identifying current technological gaps, and ensuring the design aligns with athletic performance needs.

3.1.2 Brainstorming and System Design

This phase will have the UPV Computer Science and PE Department as the resource persons. This stage will be about the development of the design concept integrating infrared sensors, LED light modules, and speakers for multimodal stimuli, as well as the UI of the software. The consultations and creation of ideas will take place at the researchers' personal workstations. This phase is to conceptualize an efficient, portable, and user-friendly device and software tailored for various racket sports scenarios.

3.1.3 Prototype Development and Programming

This phase will involve the researchers in working closely with the adviser to guide them in the development of the prototype. This stage will be about the assembly of the hardware components(IR sensors, microcontroller, LED indicators, and audio modules) and develop an accompanying application for control and data management. Algorithms will be designed to measure response latency and agility metrics accurately. This stage will take place at the researchers' personal workstations and the CAS computer laboratories. This stage aims to produce a working prototype capable of recording and analyzing athlete response data effectively, validating the proposed system's technical feasibility.

3.1.4 Testing and Experimentation

In this phase, the researchers will work closely with the UPV PE department and atheletes as they will serve to be the main observers and participants for the trials. This is the stage where the researchers will conduct the controlled trials to measure response time and agility improvements among the participants using the device. Data will be collected across multiple sessions to ensure the reliability and repeatability. Statistical analysis will be used to evaluate system effectiveness. This will take place in the UPV covered court. This stage will give an empirical validation on the system's impact on athlete performance and refine device parameters for optimal training outcomes.

3.1.5 Evaluation and Refinement

The researchers will be working closely with technical advisors and sports performance analysts for guidance in evaluation. This is the stage where the researchers will give an analysis on the experimental results, identify potential error, and gather feedback from the athletes and coaches. Redesigning and recalibration of system components based on user experience and performance data will also be included in this phase. This phase will take place at the researchers personal workstations and CAS computer laboratories. This stage will aid in the improvement of the system accuracy, usability, and durability, ensuring the device meets practical and scientific standards before final deployment.

3.1.6 Documentation and Reporting

This phase will involve the research adviser to help the researchers in proper documentation and reporting. In this stage, the researchers will compile all research findings, design specifications, performance data, and analysis into a formal technical report and academic paper. This will take place at the researchers' personal workstations. This phase will ensure transparency, replicabilty and academic dissemination of the study's result and methodologies.

3.2 Calendar of Activities

The Table 3.1 presents the chronological schedule of research activities from January to July, outlining the key phases of the study—from research and system design to prototype development, testing, and documentation. Each activity is strategically planned to ensure systematic progress and timely completion of the light-based reaction training system project.

Table 3.1: Timetable of Activities

Activities (2026)	Jan	Feb	Mar	Apr	May	Jun	Jul
Research and Consultation	●●						
Brainstorming and System Design	●●	●					
Prototype Development and Programming		●●●					
Testing and Experimentation		●	●●●●				
Evaluation and Refinement				●●●●	●●●●		
Documentation and Reporting	●●	●●●●	●●●●	●●●●	●●●●	●●●●	●●

Chapter 4

System Prototype

4.1 System Design and Architecture

This study will employ components to gather accurate measurements of reaction time. The device will be composed of one master controller and multiple stations. The study will use the ESP-NOW protocol to achieve wireless connection between the main controller and the stations. ESP-NOW is a wireless communication protocol defined by Espressif which enables multiple ESP based microcontrollers to communicate wirelessly. It is a quick and low-power way to handle connection that is based on the data link layer to achieve faster transmission. The main controller will be the master for the station controllers who will send commands and where data will be gathered and sent to a web-based player development tracker.

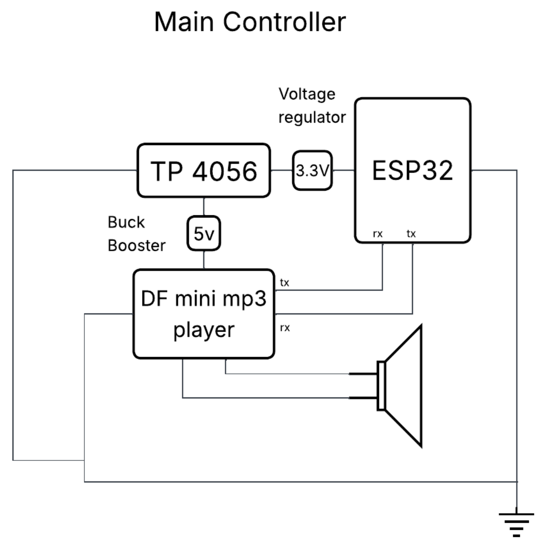

Figure 4.1: Schematic Circuit Diagram of the Master Controller

4.1.1 IOT Components

In the Figure 4.1 shows the schematic circuit diagram of the main or master controller. It will use a standard ESP32 controller who will handle the sending of commands to the smaller stations on what they will be performing as well as gathering the data from the stations and sending them to a web based player development tracker where the data will be displayed. A python app will be used to display the data sent by the main controller and will then be uploaded online in the firebase online database. Other components that the main controller has is the DF mini mp3 player module which will be responsible in playing audio sounds for trainings that need audio queue. The audio files will be stored in an SD card for the module to read. It is also connected to a 3W speaker to help amplify the sound it needs. All of these will be powered by an 3.7v 18650 battery. A TP 4056 module with protection will be used to safely charge the battery without overcharging it. A voltage regulator for 3.3v will be connected from it to stably supply the needed voltage of the ESP32. A step up power module will also be connected to the power source to produce 5v power for the DF mini mp3 module and the 3w speakers.

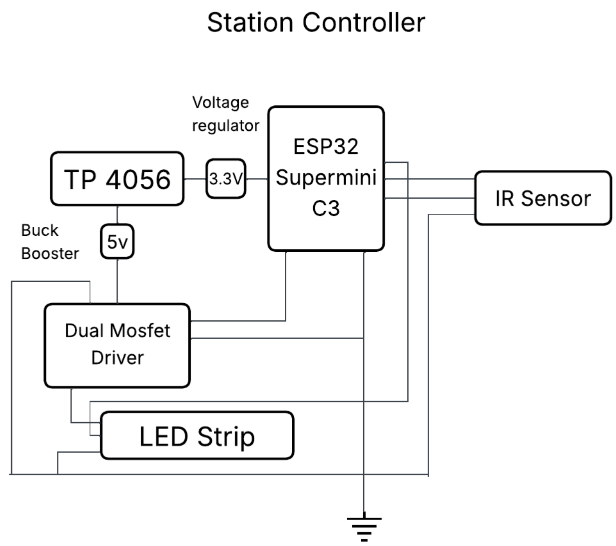

Figure 4.2: Schematic Circuit Diagram of the Station Controller

For the station nodes, the Figure 4.2 shows its circuit schematic diagram. An ESP32 super mini C3 is used. It is used as it has a smaller footprint and the sensors needed doesn't exceed the amount of its usable GPIO pins. It will receive commands from the main controller and will execute them. A programmable led strip is connected and will change depending on the command as well as will be turned off by the infrared sensor connected to the station controller. The station controller will then record the reaction time of the performer and will then send the data to the main controller. Similar to the main controller, the station controller will be powered by an 3.7v 18650 battery with a TP4056 module with protection for charging. Again, a voltage regulator for a steady supply of 3.3v will be used to power the station controller and a step up power module to 5v to power the led. The led however will be connected to a dual mosfet driver connected to the station controller to act as a switch for the 5v led strip.

Appendix A

Appendix

Appendix B

Resource Persons

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