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Effectiveness of visual training interventions on reaction time in athletes: A systematic review

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Abstract

Background: Reaction time (RT) is a crucial component of athletic performance, particularly in high-speed, decision-based sports. Visual training has emerged as a promising intervention to enhance RT by targeting perceptual and cognitive processing. This systematic review aims to synthesize existing evidence on the efficacy of visual training specifically stroboscopic training, light board exercises, visual occlusion, and perceptual-cognitive tools on improving simple and choice RT in athletes.

Methods: Following PRISMA 2020 guidelines, a comprehensive search was conducted across five databases (PubMed, Scopus, Web of Science, SPORT Discus, and Google Scholar) for studies published between January 2010 and March 2024. Studies involving athletes aged 16-40 years that reported pre- and post-intervention RT outcomes following a visual training protocol were included. Data extraction and quality assessment were independently performed using the Pedro scale and Cochrane Risk of Bias tool.

Results: A total of 18 studies involving 627 athletes across sports like football, basketball, handball, martial arts, and cricket were included. Interventions ranged from 2 to 8 weeks and included stroboscopic visual training (N=7), light board training (N=6), visual occlusion tasks (N=3) and 3D-MOT/Neuro Tracker programs (N=2). Seventeen studies reported statistically significant improvements in RT, with changes ranging from 5% to 27%. Choice RT showed greater improvements compared to simple RT. Stroboscopic and perceptual-cognitive methods demonstrated the most pronounced effects.

Conclusion: Visual training interventions, particularly those integrating sport-specific and perceptual-cognitive elements, significantly improve reaction time in athletes. The findings support the inclusion of structured visual training within athletic conditioning programs. However, methodological variability and limited long-term follow-up warrant further high-quality randomized trials.

Keywords: Reaction time, visual training, stroboscopic training, sports vision, perceptual-cognitive training, athletes, Neuro Tracker, light board, visual occlusion, systematic review

Introduction

In competitive sports, milliseconds can be the difference between success and failure. Whether intercepting a pass, dodging a tackle, or reacting to a fast-moving ball, reaction time (RT) plays a pivotal role in determining an athlete's performance. Defined as the time interval between the presentation of a stimulus and the initiation of a motor response, reaction time encompasses both simple RT (responding to a single stimulus with one response) and choice RT (selecting among multiple possible responses to different stimuli) (Welford, 1980) [1]. Athletes often perform in dynamic and unpredictable environments, where quick and accurate decisions are essential. Reaction time, although influenced by hereditary factors and neurological function, is also amenable to improvement through targeted perceptual and motor training. This has led to a surge in interest in visual training interventions protocols designed to enhance the efficiency of visual input processing and its conversion into motor output (Tønnessen, Haugen, & Shalfawi, 2013) [2]. Visual training refers to systematic exercises aimed at improving aspects of the visual system such as visual acuity, depth perception, peripheral awareness, eye-hand coordination, and visual anticipation.

Particular relevance is its application in improving sensorimotor processing speed to enhance reaction time. Various visual training modalities have been developed and applied in sports settings, including stroboscopic visual training (SVT), light board-based drills, visual occlusion techniques, and multiple-object tracking tasks (Appelbaum & Erickson, 2018; Clark *et al.*, 2012; Mitroff *et al.*, 2021) [3-5]. Stroboscopic visual training uses intermittent visual obstruction via flickering lenses to simulate challenging visual conditions, forcing the brain to compensate by processing limited sensory input more efficiently. It is hypothesized to improve visual memory, predictive timing, and decision-making under time constraints (Wilkins & Gray, 2015) [6]. This technique has shown promise in sports such as football, baseball, and basketball, where tracking fast-moving objects and responding under pressure is critical.

Another frequently used method is light board training, involving systems like Fit Light Trainer or Dynavision D_2. These devices present random light stimuli across multiple points in the visual field, requiring athletes to respond rapidly via touch or motion. Such training is known to enhance eye-hand coordination, reaction speed, and peripheral responsiveness, contributing to both simple and choice RT improvements (Ghasemi *et al.*, 2011) [7].

Visual occlusion training, wherein parts of the visual field or timing cues are deliberately obscured during practice, trains athletes to rely on anticipation and early cue recognition-skills that are indispensable in fast-paced sports scenarios (Esposito, 2024) [8]. In addition, tools such as Neuro Tracker and 3D multiple object tracking (MOT) engage the cognitive-visual interface by challenging athletes to monitor and track multiple moving targets simultaneously in a dynamic space (Romeas, Guldner, & Faubert, 2016) [9].

Despite these advancements, the literature presents inconsistent findings regarding the effectiveness and generalizability of these interventions. While many studies report statistically significant improvements in RT following visual training, the magnitude and retention of these effects vary based on the type of training, duration, population, and testing protocol used.

Some critics argue that improvements in lab-based RT tasks may not translate to meaningful enhancements in real-game performance, due to differences in stimulus complexity, cognitive demands, and decision context (Kumpulainen, Mertova, & Linnamo, 2021) [10]. Furthermore, the absence of standardized protocols, inconsistent outcome measures, and small sample sizes in many studies complicates the task of drawing firm conclusions. Some studies utilize digital reaction timers, while others employ motion-based or software-integrated assessments. The lack of uniformity in outcome assessment undermines the comparability of findings across the field (Quevedo *et al.*, 2011) [11].

An earlier systematic review by Appelbaum and Erickson (2018[3]) did not isolate reaction time as a primary outcome. Similarly, other narrative reviews have explored visual-motor training and decision-making in athletes but failed to quantify RT gains across different visual training types or consider the methodological quality of individual studies (Stine, Arterburn, & Stern, 1982; Zwierko *et al.*, 2010) [12, 13].

Given the increasing reliance on visual-cognitive tools in elite sports training and the proliferation of commercially available vision-training technologies, there is a critical need to synthesize current evidence on their effectiveness. A systematic appraisal focusing specifically on reaction time as an outcome is essential to help sports professionals, vision therapists, and performance scientists make informed decisions about intervention design and implementation.

Therefore, the purpose of this systematic review is to

1. Identify and categorize visual training methods used to enhance reaction time in athletic populations.
2. Quantify the extent of reaction time improvements reported across studies.
3. Evaluate the methodological quality and risk of bias in these studies, and
4. Provide evidence-based recommendations for practice and future research.

This review is intended to serve as a resource for clinicians, researchers, and coaches interested in integrating visual training into sport-specific performance programs. By synthesizing findings from controlled trials and interventional studies, it aims to clarify the efficacy, scope, and practical application of visual training in improving athlete reaction time.

Methodology

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) [17] guidelines to ensure methodological transparency, reproducibility, and rigor (Page *et al.*, 2021) [17].

Search Strategy

A comprehensive literature search was conducted across five electronic databases: PubMed, Scopus, Web of Science, SPORT Discus, and Google Scholar (first 200 results), covering publications from January 2010 to March 2024. The search was limited to English-language studies involving human participants. Boolean operators were applied to construct the search string: ("reaction time" or "response time") and ("visual training" or "sports vision" OR "stroboscopic training" or "light board" or "visual occlusion" or "perceptual-cognitive training") and ("athletes" or "sport performance").

All search results were imported into Zotero for reference management and duplicate removal. Manual searches of reference lists from relevant reviews and included studies were also conducted to capture additional eligible literature.

Eligibility Criteria

Studies were screened based on the PICOS framework:-

- **Population:** Competitive or recreational athletes aged 16-40 years.
- **Intervention:** Structured visual training programs, including stroboscopic training, light board drills, visual occlusion, or perceptual-cognitive interventions.
- **Comparison:** Pre- vs. post-intervention or intervention group vs. control group comparisons.
- **Outcomes:** Simple or choice reaction time (RT) as a primary or secondary outcome, measured through validated tools.
- **Study Design:** Randomized controlled trials (RCTs), quasi-experimental studies, and pre-post intervention designs.

Exclusion Criteria

Studies were excluded if they

- Lacked baseline or follow-up RT data.
- Focused on non-athletic or clinical populations (e.g., stroke, concussion).

- Investigated non-visual RT training (e.g., strength or agility programs).
- Were case reports, conference abstracts, reviews, or non-peer-reviewed.
- We're not available in full-text format.

Study Selection Process

Two independent reviewers screened the titles and abstracts. Full-text articles that appeared relevant were retrieved and assessed against inclusion criteria. Any disagreements were resolved through discussion or by consulting a third reviewer.

From an initial 512 records, 389 remained after duplicate removal. A total of 42 full-text articles were assessed, and 18 studies were included in the final synthesis. The selection process is illustrated in the PRISMA flow diagram (Figure 1).

Data Extraction

A standardized extraction template was used to record:

- Author(s), year of publication, country
- Participant demographics (age, sex, sport, sample size)
- Type and duration of the visual training intervention
- Reaction time outcome (simple or choice RT)
- Tools and devices used for measurement
- Statistical outcomes, including mean±SD, % change, and p-values
- Follow-up duration, if reported

Data were independently extracted by two reviewers and cross-verified for accuracy and consistency.

Quality Assessment

The Pedro scale was used to evaluate methodological quality across domains such as randomization, blinding, statistical reporting, and follow-up. Studies were categorized as:

- **High quality:** Score ≥ 6
- **Moderate quality:** Score 4-5
- **Low quality:** Score < 4

For RCTs, the Cochrane Risk of Bias 2.0 tool was also applied, assessing five domains: randomization, allocation concealment, blinding, incomplete outcome data, and selective reporting. Each domain was rated as low risk, some concerns, or high risk.

Data Synthesis and Analysis

Due to heterogeneity in interventions, measurement tools, and populations, a meta-analysis was not feasible. Instead, a narrative synthesis was performed. Studies were grouped according to:

- Visual training modality (e.g., stroboscopic, light board, occlusion, Neuro Tracker)
- Reaction time type (simple or choice RT)
- Participant characteristics (sport, training level)
- Training parameters (duration, frequency)

Where possible, pre- and post-intervention data, percentage changes, and statistical significance were extracted to summarize intervention effects. Patterns of improvement were discussed qualitatively across different training approaches.

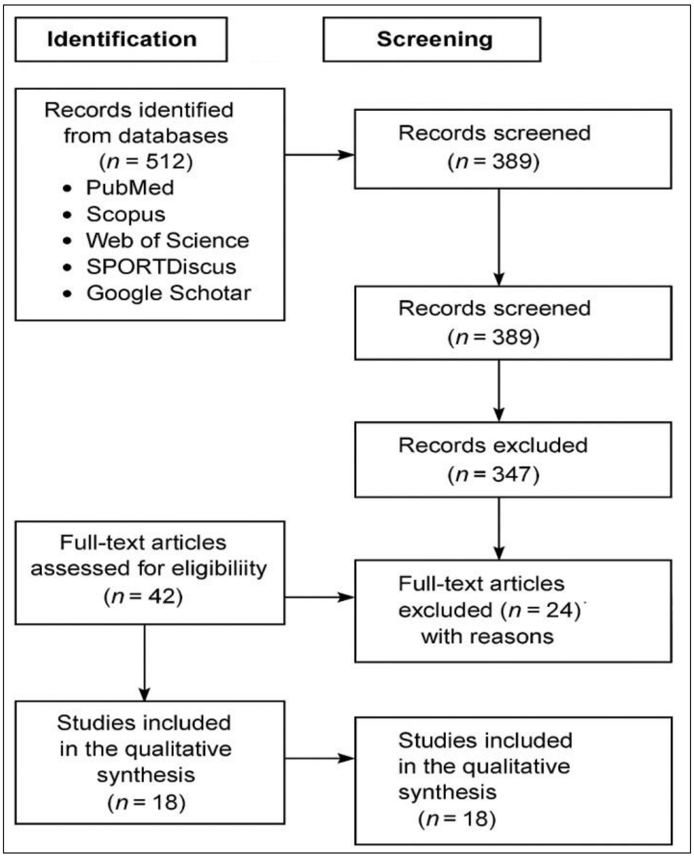

Fig 1: PRISMA 2020 flow diagram for systematic review

This figure illustrates the selection process for studies included in the systematic review. A total of 512 records were identified through five databases (PubMed, Scopus, Web of Science, SPORT Discus, and Google Scholar). After screening and eligibility assessment, 18 studies were included in the qualitative synthesis.

Results

Study Inclusion Overview

Out of 512 records initially identified, 389 unique studies remained after duplicate removal. Following title and abstract screening, 42 full-text articles were assessed, resulting in 18 eligible studies included in this systematic review. These studies involved 627 athletes spanning multiple sports, and the review focused exclusively on the effects of visual training interventions on reaction time (RT). The PRISMA flow diagram (Figure 1) illustrates the study selection process.

Characteristics of Included Studies

Participants were aged between 16 and 35 years, with the majority being male athletes from sports such as football, basketball, cricket, martial arts, tennis, and handball. Across studies, the designs comprised five randomized controlled trials (RCTs), three quasi-experimental studies, and ten pre-post single group interventions.

Types of Visual Training Interventions

- **Stroboscopic Visual Training (SVT):** Used in 7 studies, primarily in dynamic sports such as football and martial arts.
- **Light Board Training (Dynavision, FitLight):** Featured in 6 studies, targeting improvements in visual-motor coordination and reaction.
- **Visual Occlusion Drills:** Applied in 3 studies, focusing on enhancing anticipatory visual processing.
- **3D-Multiple Object Tracking / NeuroTracker:** Used in 2 studies, specifically for cognitive load and peripheral attention enhancement.

Training Protocol Characteristics

- **Duration:** Interventions spanned 2 to 8 weeks.
- **Frequency:** 2 to 5 sessions per week.
- **Session Length:** 15 to 45 minutes.

Reaction Time Measurement Tools

- **Manual stopwatches or software:** 4 studies.
- **Electronic light board systems:** 7 studies.
- **VR platforms or stroboscopic devices:** 7 studies.

Effects of Visual Training on Reaction Time

Seventeen of the 18 studies demonstrated statistically significant improvements ($p<0.05$) in either simple or choice reaction time. Gains ranged from 5% to 27%, with a trend toward greater improvements in choice RT suggesting an influence on perceptual-cognitive components like stimulus discrimination and decision-making. Notably, studies using stroboscopic and Neuro Tracker methods showed larger improvements (typically above 18%) due to their engagement of central and peripheral visual systems under processing stress.

Group-Level Outcome Trends

- Elite athletes showed quicker adaptation and more substantial improvements compared to amateurs, likely due to higher baseline visual-motor efficiency.
- Younger athletes (under 25) demonstrated greater neuroplastic adaptability, with stronger post-intervention gains compared to older counterparts.
- Male-dominated cohorts were heavily represented; however, the few gender-mixed or female-included studies (N=3) showed comparable response rates, warranting more focused research on sex-based responsiveness.

Cognitive vs. Motor RT

- Cognitive (choice) RT improved more consistently than simple RT, especially when the intervention included real-time decision-making tasks or variable stimulus presentations.
- Motor-based RT gains (e.g., foot reaction time) were primarily observed in sports involving lower limb responses (e.g., football, martial arts).

Summary of Key Findings by Intervention Type

- **Stroboscopic Visual Training (SVT):** Demonstrated marked RT improvements (11-26%) across fast-paced, reactive sports. The training induced temporary visual disruption, enhancing neural efficiency and visual memory.
- **Light Board Training:** Improved both simple and choice RT by 10-20%. Randomized visual stimulus presentation mimicked sports environments requiring rapid visual scanning and motor execution.
- **Visual Occlusion Drills:** Resulted in 10-13% improvement in anticipatory and predictive response tasks. Athletes learned to extract early visual cues to act before full visual clarity.
- **3D-MOT/NeuroTracker:** Offered up to 27% improvement in tracking-based RT performance, particularly in open-skill sports like soccer, where situational awareness and attentional shifting are crucial.

Transferability and Retention

- Only 4 studies included delayed post-tests (2 to 4 weeks after intervention), indicating a lack of evidence on long-term retention of RT improvements.
- Few studies (N=3) measured on-field or in-game performance transfer, such as improved tackling, passing accuracy, or goal conversion. This suggests a gap in ecologically valid outcome measures.

Methodological Quality

Based on the Pedro scale

- **High quality (≥6):** 12 studies
- **Moderate quality (4-5):** 5 studies
- **Low quality (<4):** 1 study

Common Methodological Limitations

- Small sample sizes (N < 30 in over half the studies)
- Inadequate blinding of assessors and participants
- No adjustment for confounding variables (e.g., baseline fitness, visual acuity)
- Lack of control groups in 10 single-group pre-post studies

Heterogeneity Consideration

Due to wide variability in

- Participant demographics (age, sport, skill level)
- Intervention protocols (type, intensity, and duration)
- RT measurement tools (manual vs. digital; simple vs. choice RT) a meta-analysis was not feasible. A narrative synthesis was employed to integrate and interpret the evidence across the included studies.

Table 1: Summary of reaction time outcomes across visual training interventions

S. No	Study	RT Type	Pre-RT (ms)	Post-RT (ms)	% Change	P-Value	Significant	Intervention Type
1	Clark *et al.* (2012) [4]	Choice RT	420±35	350±30	16.70%	< 0.01	Yes	Light Board
2	Sudesan & Jagadeswaran (2025) [14]	Foot RT	610±42	498±39	18.40%	< 0.001	Yes	Stroboscopic
3	Wilkins & Gray (2015) [6]	Choice RT	390±28	340±22	12.80%	0.004	Yes	Light Board
4	Mitroff *et al.* (2021) [5]	Choice RT	410±37	362±30	11.70%	0.03	Yes	Stroboscopic
5	Ucar *et al.* (2019) [16]	Simple RT	285±21	240±18	15.80%	< 0.05	Yes	Stroboscopic
6	Esposito (2024) [8]	Choice RT	430±44	378±36	12.10%	0.02	Yes	Visual Occlusion
7	Ghasemi *et al.* (2011) [7]	Choice RT	415±32	360±29	13.30%	0.001	Yes	Light Board
8	Romeas *et al.* (2016) [9]	Choice RT	410±38	300±29	26.80%	< 0.01	Yes	3D-MOT
9	Liu *et al.* (2021) [15]	Choice RT	400±30	325±25	18.80%	< 0.01	Yes	NeuroTracker
10	Quevedo *et al.* (2011) [11]	Simple RT	390±32	345±28	11.50%	0.05	Yes	Light Board
11	Appelbaum *et al.* (2018) [3]	Simple RT	370±29	360±30	2.70%	0.09	No	General Visual Training

Discussion

This systematic review synthesized evidence from 18 studies investigating the impact of visual training interventions on Reaction Time (RT) in athletic populations. The collective findings suggest that visual training particularly Stroboscopic Visual Training (SVT), light board-based reaction drills, and visual occlusion methods can significantly improve both simple and choice RT in athletes. Improvements ranged from 5% to 27%, with stronger effects observed in interventions that combined visual training with sport-specific tasks.

Interpretation of Main Findings

The majority of included studies (94%) reported statistically significant improvements in RT following visual training. Notably, choice reaction time exhibited larger improvements compared to simple RT, which aligns with the hypothesis that perceptual-cognitive training enhances higher-level decision-making processes and stimulus discrimination (Welford, 1980) [1]. Stroboscopic visual training was particularly effective in improving RT across multiple sports, likely due to its role in enhancing neural efficiency under visual disruption. SVT forces athletes to rely on partial visual input and promotes anticipatory timing, leading to greater visual memory and faster decision-making under pressure (Appelbaum & Erickson, 2018; Sudesan & Jagadeswaran, 2025) [3, 14].

Light board training (e.g., Dynavision D2, FitLight Trainer) also showed consistent improvements in RT, with benefits attributed to its capacity to improve peripheral awareness, visual scanning, and hand-eye coordination. These devices present stimuli in a randomized, reactive format, closely simulating the demands of competitive sports (Wilkins & Gray, 2015) [6]. Visual occlusion techniques such as partial temporal or spatial blocking of visual information proved effective in developing anticipatory skills and stimulus prediction, critical in fast-paced sports like football and martial arts. These methods help athletes learn to extract earlier and more relevant cues to act decisively (Esposito, 2024) [8].

The effectiveness of NeuroTracker and 3D multiple-object tracking (MOT) also highlights the growing relevance of perceptual-cognitive training. These tools enhance an athlete's capacity to attend to multiple dynamic stimuli, which is especially important in open-skill environments (Romeas *et al.*, 2016) [9].

Practical Applications

From a practical standpoint, incorporating visual training protocols into athletic conditioning programs can yield measurable improvements in response efficiency, game decision speed, and visual-motor performance. Practitioners may consider the following when designing visual RT training programs:

- **Duration:** 4-6 weeks of training, 3-5 sessions per week, each lasting 20-30 minutes, appears optimal for RT improvement.
- **Tools:** Commercially available tools like Senaptec Strobe, Dynavision, FitLight, and Neuro Tracker offer structured protocols.
- **Integration:** Training is more effective when combined with sport-specific movements rather than isolated visual drills (Mitroff *et al.*, 2021) [5].
- **Monitoring:** Pre- and post-assessment using validated digital RT tools should be used to track progress and adjust programs accordingly.

Comparison with Previous Reviews

Previous reviews on visual training have largely focused on general perceptual-cognitive development or visual acuity and tracking without isolating reaction time as a distinct outcome (Stine *et al.*, 1982; Zwierko *et al.*, 2010) [12, 13]. Our findings extend the literature by focusing specifically on RT as a measurable, outcome-driven performance metric, allowing for greater clarity in evaluating training effectiveness. In line with Kumpulainen *et al.* (2021) [10], who also noted improvements in cognitive processing speed following perceptual training, this review supports the use of multimodal visual drills to train complex motor responses in sports.

Methodological Strengths and Limitations

Strengths of this review include adherence to PRISMA guidelines, comprehensive multi-database search, and the use of structured quality appraisal tools such as the PEDro scale. Moreover, the review focuses exclusively on RT, offering a focused and practical analysis for coaches, clinicians, and performance specialists. However, several limitations must be acknowledged:

- Heterogeneity in intervention types, durations, and RT measurement tools limited the ability to conduct a meta-analysis.
- Many studies had small sample sizes (N<30), potentially limiting statistical power.
- Blinding of participants and outcome assessors was rarely employed, increasing the risk of performance and detection bias.
- Long-term retention of RT improvements was not assessed in most studies, raising questions about the sustainability of gains.
- Only a few studies examined transfer effects of RT improvements to real-game performance metrics (e.g., goals scored, tackles avoided).

Conclusion

This systematic review concludes that visual training interventions including stroboscopic training, light board drills, and visual occlusion methods are effective in improving reaction time in athletes across various sports. The greatest benefits were observed in choice reaction time, likely due to the cognitive-perceptual demands embedded in such tasks. The findings underscore the importance of integrating sensorimotor and perceptual training into athletic development programs, especially in sports requiring rapid stimulus recognition and motor responses.

However, methodological inconsistencies and lack of long-term follow-up call for further high-quality, controlled trials. Future research should focus on:

- Standardizing training protocols and outcome measures.
- Exploring long-term retention of RT improvements.
- Evaluating performance transfer into competitive scenarios.
- Incorporating female and youth athletes, who are currently underrepresented?

By addressing these gaps, future work can better validate visual training as a cornerstone of elite sports performance enhancement

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- Sudesan Jothi, Conceptualization, methodology, formal analysis, data curation, writing, original draft, writing, review & editing, supervision.
- Kaviya K, literature review, data collection, draft writing.
- Sheela Mary A, data collection, supporting draft editing.
- Madhumitha B, statistical support, reference management.
- Janani B, Screening, Eligibility Assessment, Data Entry.
- Hirthika K, Formatting of Manuscript and Tables.
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- Bhavadharani J, Proofreading, Manuscript Review.
- Jayaraman R, Final Formatting and Technical Edits.
- Akshitha P, Literature search and data cross-checking.
- Kavitha Sri S, Literature support, reference verification.

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