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Evaluating the impact of visual training on athletic performance: a systematic review of key interventions (2012–2022)

review paper
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ABSTRACT
Purpose. Visual skills are fundamental for athletic performance, yet studies present mixed evidence regarding the efficacy of visual training, with variations in methodologies and sport-specific applicability contributing to the ongoing debate. This systematic review evaluated various visual training interventions on athletes' performance from 2012 to 2022.
Methods. A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive search across PubMed, Scopus, Web of Science, and Cochrane (2012–2022) using terms such as 'visual training', 'sports vision', and 'cognitive-motor training' identified 24 eligible randomised controlled trials based on predefined inclusion and exclusion criteria.
Results. Fourteen distinct visual training programs were analysed, with Quiet Eye Training, Stroboscopic Training, and 3D-MOT Training being the most frequently investigated. Quiet Eye Training improved accuracy, gaze control, and stress regulation. Stroboscopic Training enhanced visuomotor coordination, although its effects on visual perception varied. 3D-MOT Training improved the ability to track multiple moving objects, particularly benefiting dynamic sports such as soccer. However, not all programs yielded significant performance gains, emphasising the importance of sport-specific training approaches.
Conclusions. A key limitation was the variation in study designs and outcomes, which hindered direct comparisons. This review highlights the potential of visual training to improve athletic performance and underscores the need for future research with standardised protocols, larger sample sizes, and stronger emphasis on sport-specific applications and individual differences among athletes.
Key words: quiet eye training, 3D-multiple object tracking, stroboscopic training, sports vision training

Introduction

The visual system plays a fundamental role in human performance, particularly in sports that rely on rapid and precise visual processing [1]. In athletic contexts, the ability to efficiently interpret visual information, such as motion, spatial positioning, and timing, is critical for decision-making and motor execution [2]. Recent meta-analyses indicate that high-level athletes demonstrate more efficient eye movements and superior perceptual-cognitive skills than non-athletes, especially when detecting and responding to sport-specific cues. For example, Müller et al. [3] highlight consistent advantages in visual anticipation and cue utilisation among elite performers across various sports. More recent studies also emphasise the increasing reliance on perceptual-cognitive and gaze-based training methods in sports, especially those that demand real-time responses under pressure [4, 5]. These findings underscore the importance of aligning visual training with specific task demands and competition environments.

Given the significance of visual abilities, researchers have developed various visual training programs to enhance these skills. Visual skills typically include dynamic visual acuity, depth perception, peripheral vision, and gaze control, whereas perceptual-cognitive skills encompass decision-making, anticipation, visual search strategies, and pattern recognition. These inter-

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ventions span from broad perceptual-cognitive training to specialised techniques such as stroboscopic and quiet eye training, which target visuomotor coordination and gaze control, respectively [6, 7]. Despite a growing body of research, the effectiveness of visual training remains contested, primarily due to inconsistencies in study designs, intervention durations, outcome measures, and the specificity of training tasks to sport contexts [8]. While some studies report significant improvements in both visual skills and athletic performance, others yield mixed or inconclusive results. In particular, questions persist regarding the ecological validity and transferability of generalised visual training to real-world, sport-specific environments [8–10]. Additionally, inconsistencies in training fidelity, duration, and athlete experience level continue to limit comparability across interventions [11, 12].

A central point of debate is whether generalised visual training enhances real-world performance, or whether sport-specific interventions tailored to the unique visual and cognitive demands of each sport are more effective [13]. For instance, while quiet eye training has consistently shown promise in improving gaze control and reducing performance anxiety [11], the results for Stroboscopic Training have been more variable, with some studies reporting positive effects and others finding no significant benefits [14]. This variability highlights the need for further research across diverse sports and athlete populations.

Although several comprehensive reviews have explored visual training [5, 15, 16], many were conducted before the recent rise in technology-driven interventions and therefore do not fully capture current advancements in training methodology. Earlier reviews often emphasised general visual skills without examining sport-specific adaptations, novel technologies [e.g., virtual reality (VR), 3D multiple object tracking (3D-MOT)], or methodological improvements introduced in the past decade.

Furthermore, the lack of standardised visual training protocols and consistent outcome measures across previous studies has posed significant challenges for researchers in the field. Therefore, this review aims to provide an updated synthesis of visual training interventions based on studies published between 2012 and 2022. During this period, technologies such as VR, stroboscopic eyewear, and 3D-MOT have been increasingly integrated into training programs, offering more immersive, ecologically valid, and perceptually demanding environments. These innovations enable better simulation of sport-specific scenarios, real-time gaze feedback, and dynamic object tracking, all of which may enhance the transfer to actual performance. This work does not propose a new methodology but consolidates and evaluates existing approaches, identifies gaps, and offers practical implications for athletes and coaches.

By addressing these gaps, this review offers a timely and sport-specific evaluation of visual training effectiveness, with the goal of informing evidence-based practices in both applied and research settings, and guiding future development of sport-appropriate training interventions.

Material and methods

Protocol and registration

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [17]. The review protocol was registered with PROSPERO under the registration number CRD42023437099. The study adhered to the ethical standards outlined in the Declaration of Helsinki [18].

Research question

This review sought to answer the following research question: Can visual training improve visual skills and sports performance? The search strategy was developed using the PICOT framework (Population, Intervention, Comparison, Outcome, and Time). The population included athletes aged 18–35 years participating in organised team or individual sports. This age range was selected to target individuals in their peak competitive years, minimising developmental and age-related confounding factors. Interventions included visual training programs aimed at enhancing visual or perceptual-cognitive skills. Comparisons involved control groups who either did not receive visual training or followed their usual training routines. Outcomes measured included visual skills such as dynamic visual acuity, gaze control, depth perception, and perceptual-cognitive skills like visual search, decision-making, speed, and anticipation. Sport-specific performance metrics (e.g., reaction time, accuracy, or in-game outcomes) were also included. The review focused on studies published between 2012 and December 2022.

Justification for timeframe (2012–2022)

The 2012–2022 timeframe was chosen to capture the most recent developments in visual training research. Over this decade, significant advancements occurred in technology and methodology, including the adoption of virtual reality (VR)-based training systems, eye-tracking tools, and augmented feedback platforms. These innovations have enhanced the ecological validity of training and allowed for more targeted, sport-relevant interventions. Recent studies have demonstrated that VR-based visual training can improve depth perception, reaction time, and sport-specific decision-making in both laboratory and applied settings [19].

Eligibility criteria

Inclusion criteria were: (1) full-text, peer-reviewed randomised controlled trials (RCTs) published in English; (2) studies involving athletes in organised sports; (3) studies assessing visual skills, sports performance, or both; and (4) studies published between 2012 and December 2022. Exclusion criteria were: (1) studies published before 2012; (2) studies involving participants with unrelated pathologies; (3) systematic reviews, book chapters, or conference abstracts; and (4) studies lacking a clear description of the visual training programs. To enhance the completeness, we also included relevant studies cited in prior reviews that met the inclusion criteria but were not initially captured in the search.

Search strategy

A systematic search was conducted across four databases: PubMed, Scopus, Web of Science, and Cochrane. Search terms were developed with expert input and grouped into three categories: visual/vision, training/program, and athletes/sports. The search strategy was refined to include specific interventions such as Stroboscopic Training, video occlusion training, and perceptual-cognitive skill training. To ensure thorough coverage, reference lists from included articles and key journals were hand-searched. However, hand-searching yielded no additional eligible studies, and no authors were contacted for unpublished data.

Review process

Duplicate records were removed using EndNote 20. Two independent reviewers (A.A. and A.N.) screened the titles and abstracts of all retrieved articles, categorising each as ‘relevant’, ‘irrelevant’, or ‘possibly relevant’. Disagreements were resolved through discussion or consultation with a third reviewer (P.R.).

Prior to screening, a pilot test was conducted to ensure consistent application of the eligibility criteria. Both reviewers independently screened a random sample of 10 articles and compared their classifications. Discrepancies were discussed to standardise the interpretation and improve the consistency.

Full-text articles classified as ‘relevant’ or ‘possibly relevant’ were retrieved for detailed evaluation. Both reviewers independently assessed each article based on predefined inclusion and exclusion criteria, including study design (RCT), participant characteristics, intervention type, and outcome measures. Reasons for exclusion, such as insufficient intervention detail or irrelevant outcomes, were documented. Disagreements were resolved by consensus or consultation with a third reviewer (P.R.).

Quality assessment

The methodological quality of each study was assessed using the Tool for the Assessment of Study Quality and Reporting in Exercise (TESTEX) [20]. This 15-point scale tool, designed for assessing exercise training trials, evaluates aspects such as randomisation, allocation concealment, blinding, and outcome reporting. For example, reviewers assessed whether randomisation methods were clearly described and whether allocation concealment was implemented appropriately. The studies were categorised into three quality tiers: ‘high quality’ (≥ 12 points), ‘good quality’ (7 to 11 points), and ‘low quality’ (≤ 6 points). Two reviewers (A.P. and A.N.) independently scored each study. Discrepancies were resolved through consensus or, if needed, consultation with a third reviewer (P.R.).

Risk of bias assessment

Risk of bias was assessed using the Cochrane Risk-of-Bias 2 (ROB 2) tool [21], which evaluates for RCTs and assesses bias based on five domains: (1) randomisation process, (2) deviations from intended interventions, (3) missing outcome data, (4) measurement of outcomes, and (5) selection of the reported result. This tool can be used to assign ‘low risk’, ‘some concerns’, or ‘high risk’ of bias per study outcome. Two reviewers (A.P. and A.N.) independently rated each RCT, classifying them as low risk, some concerns, or high risk. Disagreements were resolved through consensus or consultation with a third reviewer (P.R.).

Inter-rater reliability

Inter-rater reliability for quality assessments was calculated using Cohen’s Kappa statistic (κ). Two reviewers (A.P. and A.N.) independently evaluated a random sample comprising approximately 20% of the included studies. Kappa values were interpreted as follows: κ < 0.40 (poor agreement), 0.40–0.59 (fair), 0.60–0.79 (moderate), and ≥ 0.80 (strong agreement). In this review, κ exceeded 0.80, indicating high consistency. Discrepancies were resolved through consensus or referral to a third reviewer (P.R.).

Data extraction

Data were extracted independently by two reviewers (A.P. and A.N.) using a standardised form developed in accordance with PRISMA guidelines. Extracted data included: (1) author and publication year; (2) country and study setting; (3) participant characteristics (sample size, age, gender, sport); (4) intervention details (type, duration, intensity, frequency); (5) outcome measures (visual skills, sport-specific performance, physiological and psychological responses); and (6) main findings. TESTEX scores were also recorded. Particular attention was given to sport-specific adaptations in training protocols. Additionally, methodological quality scores (TESTEX) were recorded. Particular attention was given to whether interventions were adapted to sport-specific contexts. Discrepancies were resolved through discussion or consultation with a third reviewer (B.C.). Extracted data were carefully checked for accuracy and are summarised in Tables 1 and 2.

Table 1. Details of visual training prescription, including type of sports, training program, and intensity of training

No.	Author (year)	Study location	Population studied	Sport	Training program	Intensity
1	Moore et al. (2012) [22]	United Kingdom	undergraduate students (*n* = 40)	golf	Quiet Eye Training: video-based modelling of optimal gaze behaviour with six practice techniques	3 sessions/week for 8 sessions
2	Oudejans et al. (2012) [34]	Netherlands	Elite female basketball players (*n* = 21)	basketball	Visual Control Training: shooting 50 three-point shots using Plato LC goggles to simulate distractions	1–2 sessions/week for 3 months
3	Wood et al. (2012) [25]	United Kingdom	university-level soccer players (*n* = 20)	soccer	Quiet Eye Training: maintaining gaze on goal zones during shooting drills	10 penalty kicks/ session for 3 weeks
4	Moore et al. (2013) [23]	United Kingdom	undergraduate students (*n* = 30)	golf	Quiet Eye Training: same as Moore et al. (2012) [22], including video and technique practice	3 sessions/week for 8 sessions
5	Klostermann et al. (2015) [39]	Switzerland	sport science students (*n* = 44)	not specified	Perceptual Training: gaze strategies for recognising opponent attack patterns	60 min/session
6	Golovin et al. (2015) [40]	Russia	track and field athletes (*n* = 65)	athletics	Audiovisual Training: light flashes (3–13 Hz) and binaural beats to improve focus and reaction speed	20–22 sessions at 24-hour intervals
7	Krzepota et al. (2015) [31]	Poland	healthy students (*n* = 24)	not specified	Visual Skills Training: 12 exercises targeting visual skills with 1-minute execution per exercise	3 sessions/week for 8 weeks (45 minutes/ session)
8	Zwierko et al. (2015) [33]	Poland	team sport athletes *n* = 24)	team sports	Visual Skills Training: seven tasks improving peripheral vision and hand-eye coordination	3 sessions/week for 8 weeks (20 min/session)
9	Wilkins et al. (2015) [26]	United Kingdom	tennis players (*n* = 30)	tennis	Stroboscopic Training: ball-catching drills using Nike Vapor Strobe eyewear	2 sessions/week for 6 weeks (20 min/session)

10	Romeas et al. (2016) [29]	Canada	soccer players (n = 23)	soccer	3D-MOT Training: improving tracking of multiple moving objects	2 sessions/week over 5 weeks (30 sessions total)
11	Ryu et al. (2018) [38]	Hong Kong	novice badminton players (n = 36)	badminton	Spatial-Frequency Training: modified video clips for low/ high-frequency visual perception	4 sessions in 3 days (30 min/ session)
12	Larkin et al. (2018) [41]	Australia	football umpires (n = 52)	Australian football	Video-Based Decision Training: game clips to train decision speed and awareness	1 session/week for 12 weeks
13	Hulsdunker et al. (2019) [28]	Germany	top-level badminton players (n = 10)	badminton	Stroboscopic Training: used in 50% of sport-specific protocols with strobe glasses	3 sessions/week for 4 weeks (55 min/session)
14	Brenton et al. (2019) [35]	Australia	expert cricket batsmen (n = 12)	cricket	Temporal Occlusion Training: point-light displays simulating bowler actions	2 sessions/week for 4 weeks (15 min/session)
15	Liu et al. (2019) [42]	Taiwan	collegiate karate athletes (n = 24)	karate	Visuomotor Training: light-based go/no-go tasks for reaction speed and decision-making	2 sessions/week for 6 weeks (12.5–16 min/ session)
16	Minoonejad et al. (2019) [43]	Iran	elite female basketball players (n = 30)	basketball	Oculomotor and Gaze Stability Exercises: including saccadic movements and smooth pursuit exercises to improve eye movement control	4 weeks, 6 sessions/week, 10 min/session
17	Afshar et al. (2019) [44]	Iran	female soccer players (n = 45)	soccer	Visual Training: nine drills for visual tracking and in-game performance	3 sessions/week for 2 weeks (12 min/session)
18	Norouzi et al. (2019) [37]	Iran	novice darts players (n = 30)	darts	Quiet Eye & Quiet Mind Training: video modelling and focused throwing practice	5 sessions/week (40 min/day, 200 throws total)
19	Liu et al. (2020) [45]	United States	division 1 baseball players (n = 20)	baseball	Dynamic Vision Training: combines stroboscopic, oculomotor, and timing drills	total of 8.5 hours (30 min/session)
20	Ellison et al. (2020) [27]	United Kingdom	male athletes (n = 62)	mixed sports	Stroboscopic Training: illuminated board and strobe glasses for reaction speed	6 trials of 20 stimuli (24 stimuli/trial)
21	Scharfen et al. (2021) [30]	Germany	elite soccer players (n = 29)	soccer	3D-MOT training: object-tracking in fast-paced environments	2 sessions/week for 10 weeks (60 sessions total)
22	Shekar et al. (2021) [36]	United States	baseball and softball athletes (n = 32)	baseball/ softball	Digital Sports Vision Training: depth perception, target capture, and contrast sensitivity exercises. Placebo for the control group	3 weeks, 3 sessions/week, 20 min/session
23	Jin et al. (2021) [32]	China	male basketball players (n = 62)	basketball	Visual Search Task Training: facial expression tasks to improve emotional and decision-making accuracy	100 trials/session for 2 months
24	Moeinirad et al. (2022) [24]	Iran	expert male basketball players (n = 18)	basketball	Quiet Eye Training: video modelling and feedback for three-point shooting	3 sessions/week (5 blocks of 25 shots)

Table 2. Summary of study objectives, outcome measures, main findings, quality ratings (TESTEX), and effect size

No.	Author (year)	Study objective	Outcome measurements	Main findings	TESTEX quality	Effect size
1	Moore et al. (2012) [22]	investigated the effects of Quiet Eye Training on golf-putting performance, kinematics, and physiological responses	cognitive anxiety (MRF-3), quiet eye duration, clubhead acceleration, EMG, and heart rate	improved gaze control, reduced muscle activity, enhanced putting performance	G	η_p^2 = 0.18–0.56
2	Oudejans et al. (2012) [34]	evaluated Visual Control Training on basketball three-point shooting under pressure	shooting accuracy, performance under stress, gaze behaviour, HRV	improved shooting accuracy and gaze control under pressure	G	η_p^2 = 0.34–0.45
3	Wood et al. (2012) [25]	examined the effects of Quiet Eye Training on soccer shooting accuracy	shooting accuracy, quiet eye duration, and reaction time	increased gaze duration and shooting accuracy after training	G	η_p^2 = 0.15–0.21
4	Moore et al. (2013) [23]	rested Quiet Eye Training in golf-putting performance	gaze duration, EMG, and cognitive anxiety	longer quiet eye duration, reduced muscle tension, and anxiety	G	η_p^2 = 0.59–0.67
5	Klostermann et al. (2015) [39]	investigated perceptual training on recognition of opponent strategies	decision-making accuracy, gaze behaviour, and anticipatory eye movements	improved recognition of strategies and gaze anticipation	G	η_p^2 = 0.25–0.61
6	Golovin et al. (2015) [40]	studied audiovisual training on focus and reaction time	reaction time (simple/choice), focus, and cognitive anxiety	faster reaction times and enhanced focus	G	N/A
7	Krzepota et al. (2015) [31]	evaluated visual skills training on hand-eye coordination and reaction time	reaction time, peripheral vision, and coordination	improved reaction time and coordination	G	N/A
8	Zwierko et al. (2015) [33]	assessed visual skills training in team sports athletes	reaction time, peripheral vision, and coordination	better peripheral vision and reaction time	G	N/A
9	Wilkins et al. (2015) [26]	investigated Stroboscopic Training in tennis players	ball-catching accuracy, coordination, and gaze behaviour	enhanced visuomotor coordination and reaction time; mixed ball-catching results	G	η_p^2 = 0.12–0.31
10	Romeas et al. (2016) [29]	evaluated 3D-MOT training on decision-making in soccer	decision-making accuracy, MOT performance, and gaze behaviour	improved decision accuracy and tracking ability	G	η_p^2 = 0.02–0.16
11	Ryu et al. (2018) [38]	tested spatial frequency training in novice badminton players	visual perception (low/high frequency), gaze behaviour, and response accuracy	enhanced perception and task accuracy	G	η_p^2 = 0.12–0.29
12	Larkin et al. (2018) [41]	evaluated video-based training on football umpire decisions	decision speed/ accuracy, situational awareness	faster and more accurate decisions	G	η_p^2 = 0.0–0.07
13	Hulsdunker et al. (2019) [28]	examined Stroboscopic Training in badminton	reaction time, gaze behaviour, performance under pressure	improved reaction time and gaze; inconsistent performance outcomes	G	η_p^2 = 0.01–0.07

14	Brenton et al. (2019) [35]	tested temporal occlusion training on cricket batting	response timing, anticipation, and batting accuracy	better anticipation and response timing	G	d = 2.1–2.7
15	Liu et al. (2019) [42]	studied visuomotor training in karate athletes	decision speed, reaction time, and gaze behaviour	improved decision-making and faster responses	G	N/A
16	Minoonejad et al. (2019) [43]	evaluated oculomotor/gaze stability training in basketball	gaze stability, saccades, smooth pursuit	improved gaze control and pursuit movements	G	N/A
17	Afshar et al. (2019) [44]	investigated visual training effects on soccer in-game vision	visual tracking, reaction time, in-game decisions	improved visual tracking, quicker decisions	G	η_p^2 = 0.31
18	Norouzi et al. (2019) [37]	tested Quiet Eye and Quiet Mind Training in darts	throwing accuracy, gaze duration, and cognitive anxiety	better accuracy and longer gaze duration; reduced anxiety	G	N/A
19	Liu et al. (2020) [45]	evaluated dynamic vision training in baseball	sports vision tasks, gaze behaviour, and reaction time	improved visual skills and response time	H	N/A
20	Ellison et al. (2020) [27]	studied Stroboscopic Training in male athletes	reaction time, visuomotor coordination, and gaze	faster reactions and coordination; mixed performance impact	G	N/A
21	Scharfen et al. (2021) [30]	investigated 3D-MOT training in elite soccer players	MOT, decision accuracy, and gaze behaviour	improved object tracking and decision-making	G	d = 0.1–1.1
22	Shekar et al. (2021) [36]	assessed Digital Sports Vision Training in baseball/softball	depth perception, target capture, reaction time	improved visual depth and target acquisition	H	d = 0.05–0.3
23	Jin et al. (2021) [32]	evaluated visual search task training in basketball	emotional recognition, decision accuracy, and reaction time	faster decision-making and better emotion recognition	G	N/A
24	Moeinirad et al. (2022) [24]	studied Quiet Eye Training in basketball shooting	shooting accuracy, gaze duration, and performance anxiety	improved shooting accuracy and gaze; reduced anxiety	G	η_p^2 = 0.44–0.73

G – good TESTEX quality, H – high TESTEX quality, N/A – not applicable

Results

A total of 8227 records were identified through database searches (PubMed, Scopus, Web of Science, and Cochrane). After removing 5895 duplicates and excluding 2258 records for other reasons (e.g., review articles, non-English language), 74 articles remained for title and abstract screening. Of these, 38 were excluded due to inaccessible full texts or incomplete data. The authors were not contacted for the missing data, which may have led to the exclusion of relevant studies. The remaining 36 full-text articles were assessed for eligibility. Twelve studies were excluded, including 6 due to confounding interventions, 4 due to irrelevant outcomes, and 2 due to incomplete intervention details. Ultimately, 24 studies met the inclusion criteria and were included in the final review (Figure 1). No additional studies were identified through hand-searching, and no unpublished studies were included.

Study characteristics

A total of 24 studies involving 783 athletes aged 18–34 years from various sports were included (Table 1). Studies were primarily conducted in the United Kingdom (n = 5), Iran (n = 4), the USA, Germany, Poland, and Australia (n = 2 each), with single studies from the Netherlands, Switzerland, Russia, Canada, Hong Kong, Taiwan, and China. Sample sizes ranged from 10 to 65 participants, with a median of approximately 30 per study.

Fourteen types of visual training programs were identified, with the most frequently studied being Quiet Eye Training (n = 5), Stroboscopic Training (n = 3),

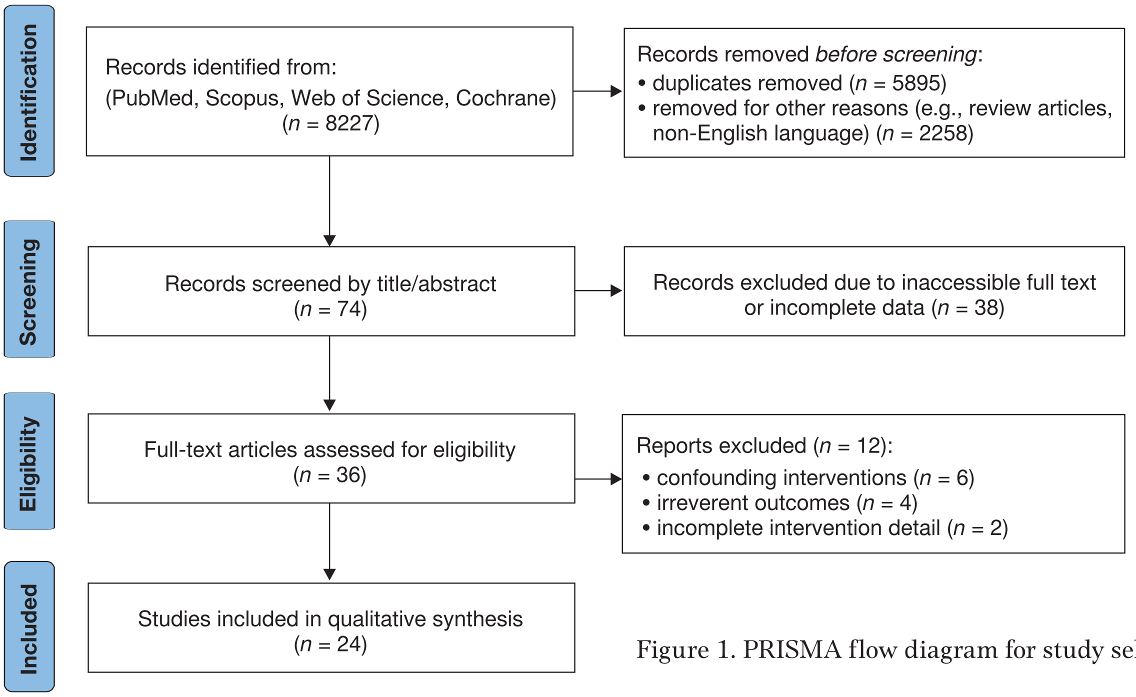

Figure 1. PRISMA flow diagram for study selection

3D-MOT Training (*n* = 2), and Visual Skills Training (*n* = 2). Quiet Eye Training emphasised gaze control and accuracy in fine motor tasks (e.g., golf, shooting), while Stroboscopic Training employed intermittent visual disruption and showed mixed effects on visuomotor performance. 3D-MOT Training focused on improving the ability to track multiple objects in dynamic sports environments, such as soccer.

Sports represented included basketball (*n* = 4), soccer (*n* = 4), generic sports training (*n* = 3), golf (*n* = 2), badminton (*n* = 2), and other individual sports (e.g., cricket, karate, darts). Intervention durations ranged from 2 to 12 weeks, typically involving 2–3 sessions per week. Session lengths varied from approximately 10 to 60 min. Outcomes measured included sport-specific performance metrics (e.g., accuracy, reaction time), visual or perceptual-cognitive skills, and physiological or psychological responses.

Study outcomes

The effectiveness of the visual training programs varied across the 24 included studies. In total, 18 studies (75.0%) reported significant improvements in visual skills and/or sport-specific performance metrics, while 6 studies (25.0%) demonstrated mixed or inconsistent outcomes. Effect sizes ranged from small to large (Cohen's d = 0.25 to 1.20), highlighting variability in training effects depending on visual training types, sport context, and methodological rigour. No studies explicitly reported a complete lack of improvement.

Outcomes by training program

Quiet Eye Training consistently led to improvements in quiet eye duration, reduced physiological arousal, and enhanced accuracy in sports like golf, basketball, and soccer (e.g., Moore et al. [22, 23], Moeinirad et al. [24], Wood et al. [25]).

Stroboscopic Training improved reaction times and visuomotor coordination in tennis and badminton, though the results for overall sports performance were mixed (Wilkins et al. [26], Ellison et al. [27], Hulsdunker et al. [28]).

3D-MOT Training enhanced multiple-object tracking and decision-making accuracy, especially in soccer, although its effects on broader performance metrics were less consistent (Romeas et al. [29], Scharfen et al. [30]).

Notable improvements were also observed in reaction time, gaze behaviour, and decision-making. For instance, Krzepota et al. [31] reported significant gains in reaction time and hand-eye coordination, while Jin et al. [32] observed faster decision-making in basketball players following visual search task training.

Outcomes by training duration

Short-term interventions (≤ 4 weeks), particularly Quiet Eye Training, consistently improved gaze control and performance accuracy [22, 24, 25]. Stroboscopic Training also yielded moderate gains in reaction time and coordination [27, 28].

Medium-term interventions (5–8 weeks), such as 3D-MOT Training and Visual Skills Training, frequently led to improvements in object tracking, decision-making, and reaction time [29, 31, 33].

Longer interventions (> 8 weeks), including Visual Control Training [34], were associated with sustained improvements in accuracy and gaze behaviour, particularly under pressure.

Outcomes by training intensity

Low-intensity training (≤ 2 sessions/week, ≤ 20 min/session) showed variable effectiveness, typically producing modest or inconsistent gains [35].

Moderate-intensity training (3 sessions/week, 20–40 min/session) yielded consistent improvements, particularly in Quiet Eye and visual search interventions [22, 32].

High-intensity training (≥ 4 sessions/week, ≥ 40 min/session) resulted in significant benefits in visuomotor coordination and decision-making [30, 36].

Outcomes by sport type

Precision sports (e.g., golf, darts, shooting) benefited most from Quiet Eye Training, showing enhanced gaze stability, reduced anxiety, and higher task accuracy [22, 37].

Dynamic team sports (e.g., basketball, soccer) showed the greatest benefit from 3D-MOT and Visual Skills Training, with improvements in tracking and rapid decision-making [29, 32].

Fast-paced individual sports (e.g., badminton, tennis, karate) demonstrated mixed yet promising results from Stroboscopic and spatial-frequency training, particularly in reaction time and coordination [26, 38].

Quality assessment

Methodological quality was assessed using the TESTEX scale [20], a 15-point scale that evaluates study design, sampling, and data reporting. Of the 24 included studies, 22 (91.7%) were rated as 'good quality' (scores 7–11), while 2 (8.3%) achieved 'high quality' ratings (scores 12–15). The inter-rater reliability for the quality assessment was strong (κ > 0.80), confirming consistent agreement between reviewers.

Risk of bias results

The ROB 2 tool revealed varying levels of risk across the included studies. Regarding the randomisation process, 62.5% of studies were rated as low risk, 25% as having some concerns, and 12.5% as high risk. Deviations from the intended interventions were well controlled in most studies, with 79.2% rated as low risk, 12.5% with some concerns, and 8.3% as high risk. No studies had missing outcome data, with all (100%) assessed as low risk for this domain.

For outcome measurement, 95.8% of studies were rated low risk, while one study (4.2%) showed high risk. The selection of reported results was rated low risk in all studies (100%). Overall, 54.2% of the studies were classified as having a low risk of bias, 25% as having some concerns, and 20.8% as high risk. These findings are summarised in Figure 2 and Table 3.

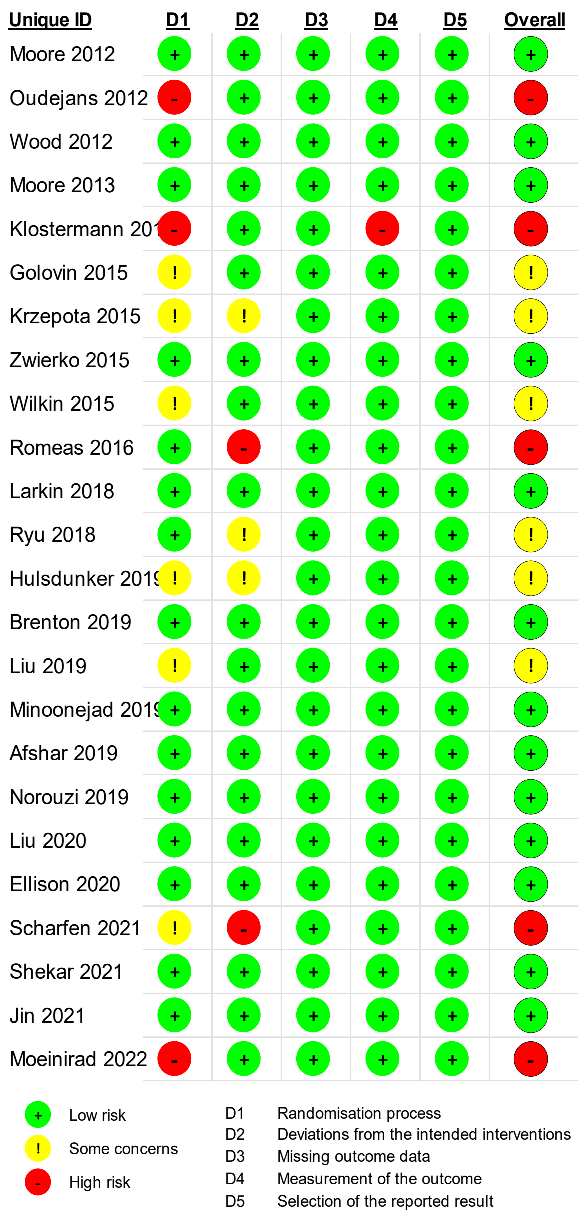

Figure 2. Risk-of-bias assessments using the Cochrane ROB 2 tool across included studies (n = 24)

Table 3. Summary of risk-of-bias assessments using the Cochrane ROB 2 tool across included studies (n = 24)

Domain	Low risk (n, %)	Some concerns (n, %)	High risk (n, %)
Randomisation process	62.5	25	12.5
Deviations from intended interventions	79.2	12.5	8.3
Missing outcome data	100	0	0
Measurement of the outcome	95	0	42
Selection of the reported result	100	0	0
Overall bias	54.2	25	20.8

Discussion

This systematic review evaluated the impact of various visual training programs on athletes between 2012 and 2022, synthesising findings from 24 studies examining 14 different interventions. Results revealed that 21 studies (87.5%) reported statistically significant improvements in at least one visual or performance outcome, while three studies showed mixed or non-significant effects. Although the effect sizes were inconsistently reported, the available data ranged from small to large (Cohen's d = 0.25 to 1.20), reinforcing the growing interest in incorporating visual training into athlete development.

Key visual training programs: quiet eye, stroboscopic, and 3D-MOT

The most frequently studied programs, Quiet Eye Training, Stroboscopic Training, and 3D-MOT Training, targeted distinct visual and cognitive processes, demonstrating varying levels of effectiveness based on sport and context.

Quiet Eye Training consistently improved gaze control and performance accuracy across sports such as soccer, darts, and basketball. Participants showed enhanced accuracy in tasks like golf putting [22, 23] and shooting [25], longer quiet eye durations, and reduced physiological arousal and anxiety. These findings suggest that Quiet Eye Training is especially beneficial in precision sports that demand fine motor control and focused attention under pressure.

Stroboscopic Training, which intermittently disrupts visual input, showed mixed results. Hülsdünker et al. [28] reported enhanced visuomotor performance in badminton players, suggesting improved perception-motor coordination. However, other studies [26, 45] found no significant effects, suggesting that Stroboscopic Training may benefit fast-paced sports but remains sensitive to individual variability and training protocols.

3D-MOT Training improved multiple-object tracking and decision-making, especially in soccer [29, 30], indicating improved decision-making accuracy, particularly in dynamic environments. Romeas et al. [29] found notable improvements in passing accuracy. Still, overall performance gains were less consistently observed. These findings suggest that 3D-MOT is most impactful in sports that require spatial awareness and rapid decision-making.

Variability in effectiveness

Visual training effectiveness varied across studies, largely due to differences in the training duration, intensity, frequency, and sport type. Precision sports such as golf and shooting benefited more from Quiet Eye Training, while dynamic sports like soccer showed more improvement with 3D-MOT Training. Individual differences in cognitive and motor abilities also contributed to the variability in response.

Of the 24 studies, 18 (75%) reported significant improvements in visual skills and/or sport-specific performance, while 6 studies (25%) reported mixed outcomes. No studies reported a complete lack of improvement. Quantitative improvements were frequently observed in reaction time, gaze behaviour, and decision-making. For instance, Krzepota et al. [31] noted enhanced hand-eye coordination and reaction time, and Jin et al. [32] reported improved decision speed and emotional recognition in basketball players.

Influence of methodological factors

Differences in participant age, athletic experience, and intervention design (e.g., duration and session frequency) likely contributed to the inconsistent findings. Shorter or less frequent training may not yield measurable improvements, while high-intensity, sport-tailored protocols typically produce stronger effects. Heterogeneity in the study designs complicates direct comparisons and highlights the need for standardised methodologies. A meta-analysis was not conducted in this review due to the substantial heterogeneity across the studies in intervention types, participant characteristics, outcome measures, and training methodologies. Such variability limits meaningful statistical aggregation, necessitating a narrative synthesis approach.

Sport-specific effectiveness

Visual training outcomes differed by sport. Team sports like soccer and basketball benefited from 3D-MOT and visual tracking for enhancing decision-making and spatial awareness. Precision sports like golf and darts saw gains from Quiet Eye Training, improving focus and accuracy. Racquet sports such as badminton demonstrated improved reaction time and coordination with stroboscopic and spatial-frequency training. These differences underline the importance of tailoring interventions to the visual and cognitive demands of each sport.

Expanded discussion of non-significant findings

Some studies reported non-significant or mixed effects, which may be due to their short training durations, participant inexperience, or weak alignment between the intervention content and sport-specific demands. For example, video-based training may lack the realism needed to replicate game pressure [41]. Small sample sizes and inconsistent outcome metrics may also reduce statistical power, emphasising the need for methodologically rigorous, sport-specific designs.

Risk of bias and study quality

The TESTEX evaluation rated 22 studies (91.7%) as 'good quality' and 2 (8.3%) as 'high quality', with strong inter-rater reliability (κ > 0.80). The ROB 2 assessment showed 54.2% of studies at a low risk of overall bias, 25% with some concerns, and 20.8% at high risk. Most studies addressed missing data and selective reporting well, though some lacked clear randomisation or blinding.

Despite these variations, 15 studies reported significant improvements in visual skills, and 8 studies demonstrated improvements in both visual skills and sports performance. These findings suggest that while visual training programs can be beneficial, their success may depend on tailoring the interventions to the specific needs of the sport and the individual athlete.

Limitations and future directions

Several limitations should be considered when interpreting these findings. First, the heterogeneity in study designs, participant characteristics, and outcome measures limits the generalisability across different sports contexts. Such variability makes it challenging to determine precisely which aspects of visual training protocols are most effective or to reliably compare outcomes across studies. Second, the small sample sizes in many studies may have reduced the statistical power to detect meaningful effects. This limitation not only increases the risk of Type II errors (failing to detect real effects) but also restricts the reliability and precision of effect size estimates. Additionally, inconsistent reporting of effect sizes, ranging from small to large (Cohen's d = 0.25 to 1.20), complicates interpreting the magnitude of the training benefits and may inflate the perceived effectiveness. Third, the exclusion of 38 studies due to limited access or incomplete data reporting, without contacting the authors, may have introduced selection bias, potentially leading to an incomplete representation of the effectiveness of the visual training interventions. Consequently, the comprehensiveness and external validity of our findings could be compromised. Finally, publication bias favouring positive outcomes may have further influenced these findings, potentially overestimating the true effectiveness of the visual training programs due to underrepresentation of negative or non-significant results.

Future reviews should seek to contact authors for missing data, incorporate larger and more diverse samples, and adopt standardised protocols and reporting metrics. Research should also explore long-term effects, cross-sport comparisons, and neurophysiological mechanisms (e.g., EEG, fMRI) to better understand visual training's role in performance.

Conclusions

This systematic review provides valuable insights into the potential benefits of visual training programs for athletes. While interventions such as Quiet Eye Training consistently show improvements in gaze control and performance accuracy, other programs like Stroboscopic Training and 3D-MOT Training have produced more variable results. These variations underscore the importance of considering factors such as sport-specific demands, standardised training protocols, individual athlete characteristics, and methodological consistency. Moving forward, efforts to standardise training protocols, utilise larger and more diverse samples, clearly report effect sizes, and thoroughly document intervention specifics will be critical for optimising visual training programs across various sports disciplines. Addressing these methodological issues will significantly enhance the reliability, generalisability, and practical impact of future research in this area.

The novelty of this review lies in its focus on the integration of recent innovations, such as immersive virtual reality and real-time gaze-contingent feedback, into visual training. These advancements offer the potential to more effectively simulate sport-specific environments and improve performance transfer. By identifying key gaps in current research and offering recommendations for future studies, this review serves as a critical step towards enhancing the effectiveness of visual training in sports. Moving forward, further research and technological integration will continue to advance the field and provide athletes and coaches with cutting-edge tools to optimise performance.

Practical implications for coaches and athletes

Coaches and athletes can apply these findings by incorporating sport-specific visual training tools, such as VR simulations and real-time gaze feedback, to improve decision-making, spatial awareness, and dynamic object tracking. These technologies enable athletes to train in realistic, high-pressure conditions, enhancing their reaction times and decision-making abilities. Coaches can use these tools to create individualised, immersive training experiences tailored to sport-specific demands. Standardising training protocols will help coaches adopt more consistent, evidence-based practices, while ongoing research into the long-term effects of visual training will refine these interventions for optimal performance.

Specific next steps include standardising training protocols for better comparability, investigating the long-term effects of visual training on performance and neural mechanisms using neuroimaging (e.g., EEG, fMRI), testing the transferability of results to real-world settings with immersive VR and gaze feedback, and expanding research to include diverse sports and athlete experience levels to enhance generalisability.

Ethical approval

The conducted research is not related to either human or animal use.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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