Piva *et al. BMC Sports Science, Medicine and Rehabilitation* (2025) 17:298
https://doi.org/10.1186/s13102-025-01368-z

BMC Sports Science, Medicine and Rehabilitation

RESEARCH

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Reduction in reaction time and improved oculomotor function following football-specific vision training in young players

Tommaso Piva[1], Valentina Zerbini[1], Anna Barducco[2,3], Silvia Mancioppi[2,3], Andrea Raisi[1,4*], Matteo Vassali[3], Gianluca Bianchini[3], Matteo Laporta[1], Erica Menegatti[5], Giovanni Grazzi[1,4,6], Gianni Mazzoni[1,6] and Simona Mandini[1]

Abstract

Background Visuomotor skills play a critical role in football performance, supporting players' ability to perceive, decide, and act effectively in dynamic environments. Although Sport Vision Training (SVT) has shown potential to improve visual and perceptual-motor abilities, the evidence remains mixed and limited by methodological variability. Cost and accessibility also represent practical challenges. This study evaluates the impact of an 8-week field-based SVT protocol on visuomotor reaction time (VMRT) and oculomotor function in young recreational football players.

Methods A total of 35 football players (Under-12 and Under-13) participated in this quasi-experimental study. Participants underwent baseline orthoptic evaluations to ensure normal visual function. VMRT was assessed using BlazePod® devices, and oculomotor function was evaluated using the Northeastern State University College of Optometry (NSUCO) test. The SVT intervention was conducted twice weekly for8 weeks, integrated into football training. Generalized linear mixed models (GLMMs) and cumulative link models (CLMMs) were used for statistical analysis.

Results Significant improvements were observed in VMRT for upper-limb tasks ($p < 0.001$), while lower-limb reaction times showed no significant change. Oculomotor performance improved, particularly in saccadic precision ($p = 0.02$) and reduction of body and head movement during saccadic tasks ($p < 0.001$). No significant improvements were found in pursuit movement accuracy ($p = 0.37$).

Conclusion The field-based SVT protocol was associated with improvements in upper-limb VMRT and specific oculomotor functions in young footballers. While these findings suggest that sport-specific SVT may enhance key visual-motor skills relevant to football performance, the quasi-experimental design limits causal interpretations.

Keywords Sport vision training, Visuomotor reaction time, Oculomotor function, Youth football, Visual training

*Correspondence:
Andrea Raisi
andrea.raisi@unife.it
[1]Center for Exercise Science and Sport, Department of Neuroscience and Rehabilitation, University of Ferrara, via Gramicia 35, Ferrara 44123, Italy
[2]Department of Neuroscience and Rehabilitation, University of Ferrara, Ferrara, Italy
[3]Orthoptics Units, Sant'Anna University Hospital, Ferrara, Italy
[4]Healthy Living for Pandemic Event Protection (HL-PIVOT) Network, Chicago, IL, USA
[5]Department of Environmental Sciences and Prevention, University of Ferrara, Ferrara, Italy
[6]Public Health Department, AUSL Ferrara, Ferrara, Italy

Introduction

Football, like most situational sports, involves a wide range of scenarios influenced by multiple variables. These include the positions of teammates and opponents, the location of the ball, and its movement in terms of trajectory, speed, and rotation across countless combinations. Players must process this information to effectively perform complex motor tasks -such as kicking, running, tackling, or goalkeeping- and to support decision-making in dynamic environments. In such high-pressure and rapidly evolving contexts, a player's ability to perceive their surroundings and make optimal decisions for subsequent actions is critical to performance [1, 2]. Research has demonstrated that elite athletes excel in perceiving and responding to sport-specific cues, showing superior accuracy and faster response times in perceptual-cognitive tasks. These findings highlight the significant role that visual and, in particular, visuomotor reaction skills play in elite sports performance [2–4]. However, exceptional visuomotor abilities in athletes are often attributed more to implicit adaptation processes driven by the sport's high visuomotor demands than to targeted training interventions. To address this, numerous Sport Vision Training (SVT) methods have been developed in recent decades to enhance visual and visuomotor functions systematically [5].

SVT methods comprise optometric tasks [3, 5], sport specific video or images [6, 7], stroboscopic interruption of vision [8, 9], use of specific lighting conditions [10] or visual-motor reaction training [11, 12]. While Sport vision training protocols have been implemented using a wide variety of methods (including optometric tasks, video stimuli, stroboscopic training, interactive light training, and visual-motor reaction exercises), the theoretical rationale behind their effectiveness is grounded in the frameworks of perceptual learning and neural adaptation. Recent models suggest that repetitive engagement in visual tasks induces plastic changes in neural circuits responsible for visual processing, thereby enhancing detection, discrimination, and response selection [13–15]. These changes reflect both bottom-up sensory refinements and top-down improvements in attention and cognitive control [14]. In sport settings, such neuroplastic adaptations can contribute to faster visuomotor responses and more efficient oculomotor behavior, ultimately supporting performance under time-constrained and complex game conditions [5]. These theoretical assumptions align with the general philosophy behind SVT programs, which are based on three key premises: (a) aspects of vision are important for particular sports, (b) these aspects of visual function can be modified through training, and (c) improvements in visual abilities can translate into improvements in on-field performance. These assumptions are commonly accepted as the conceptual foundation of SVT programs [16], yet they still require empirical validation.

Early approaches to generalized visual training applied to sport where discussed by Abernethy and Wood, reporting no evidences that such programmes led to improvements in either vision or motor performance above and beyond those resulting from test familiarity [3]. One of the reasons hypothesized for this lack of effectiveness in improving motor performance, was the lack of situation specificity in the training tasks. This approach indeed violates the notion of specificity of practice, attempting to gain improvements in specific aspects of sport skill using general forms of training [17].

Considering the application of SVT to football, Fortes et al. reported that stroboscopic vision training over an 8-week period led to improvements in decision-making skills [18]. Rodrigues et al. demonstrated that a 6-week intervention using special lighting demonstrated significant improvements in dynamic visual acuity, recognition time, sensory and motor reaction time, and peripheral identification accuracy [10]. No significant changes were observed in stereopsis, peripheral identification speed, or anticipation. Similar findings were reported by Nimmerichter et al. a 6-week video-based visual training program for young athletes was effective in improving significantly in successful decisions, response time, and reactive agility sprint time [7].

Although several individual studies have reported performance benefits following vision training, recent systematic reviews have highlighted the need for better-designed protocols and more consistent outcome measures. For example, Buscemi et al. [1] found moderate support for SVT's effectiveness in improving visual and perceptual-motor skills, though methodological heterogeneity limited generalizability. Similarly, Appelbaum and Erickson [5] pointed out that digital and stroboscopic techniques show potential, but require further validation in sport-specific settings. In this context, there is a need for protocols that can be feasibly implemented within football training environments and that specifically target the visuomotor demands of the sport.

Therefore, the primary aim of this study was to evaluate the effectiveness of a 8-week field-based SVT protocol on Visuo-Motor Reaction Time (VMRT) in young recreational football players. The secondary aim was to verify the effectiveness of the protocol in improving oculomotor function. The central hypothesis of this study is that the aforementioned SVT protocol can improve VMRT and oculomotor function in young players.

Methods

Study design

This study is a quasi-experimental study conducted from November 2023 to May 2024. Participants were recruited from a recreational football club in Ferrara (Italy), and informed consent was obtained from both minors and their guardians/parents to participate in the study. The study was conducted in accordance with the Helsinki declaration and approved by the local Ethic committee (Study Code 113-2023-Sper-UniFe). Following a baseline orthoptic evaluation to rule out significant visual deficits, participants underwent two testing sessions to assess visuomotor reaction time and oculomotor function. These sessions were separated by an 8-week SVT program.

Participants

The study included participants born between January 1, 2011, and December 31, 2012, who were actively playing football in the Under-12 and Under-13 categories. To be included in the study, participants needed to meet normal visual standards, defined as: presence of binocular vision (therefore absence of manifest strabismus), stereopsis < 120", point of convergence < 15 cm [19].

Baseline characteristics

To include only players with normal visual abilities, an orthoptic evaluation was performed to assess visual skills and the muscles involved in ocular motility. The evaluation followed a non-invasive procedure conducted individually. All assessments were performed in a standard-lit environment using artificial light. Since the assessments are qualitative and partly operator-dependent, two orthoptists conducted the evaluations, and any discrepancies were resolved with a third orthoptist. Participants reported an orthoptic history to document known vision impairments, use of glasses or contact lenses, and dominance for upper and lower limbs.

A comprehensive visual examination was carried out following an in-depth assessment of ocular health. The evaluation included tests to assess binocular vision and eye alignment: the cover test and uncover test at both far (6 m) and near (40 cm) distances to detect ocular misalignments such as heterophoria (latent strabismus) or heterotropia (manifest strabismus); and the prismatic cover test to detect any latent strabismus. Stereopsis, a key measure of depth perception, was assessed using the Frisby test (viewing distance of 40 cm, plate thickness of 6 mm, 3 mm and 1.5 mm respectively), which examines the ability to perceive three-dimensional objects at near distances without requiring specialized glasses. Additionally, ocular dominance, convergence, and ocular motility were also assessed.

Oculomotor function

Oculomotor skills were preliminarily studied through the ocular motility examination test carried out in the nine diagnostic gaze positions to ensure that there were no alterations in the movements, then the Northeastern State University College of Optometry (NSUCO) test was performed [20]. This standardized test evaluates eye and saccadic movements in three performance areas: ability, accuracy, and head movement. Each area is rated from 1 to 5, with 5 representing optimal performance. The test was performed binocularly at a distance of 40 cm, using small, coloured spheres (0.5 cm in diameter) mounted on a rod as fixation stimuli. Smooth pursuits were assessed by moving the stimulus in a circular motion (approximately 20 cm in diameter) clockwise and counterclockwise, while saccades were tested by alternating fixation between two stimuli separated by 20 cm horizontally. Scoring was determined by the examiner's observation according to predefined criteria [20, 21]. Previous research has reported moderate to high inter-rater reliability, with ICCs ranging from 0.72 to 0.88 depending on the subtest and experience of the raters [21]. In the present study, to mitigate observer bias, all evaluations were conducted independently by two trained orthoptists, and discrepancies were resolved by consensus with a third specialist.

Visuomotor reaction time

Visuo-Motor Reaction Time was assessed using BlazePod® (Play Coyotta Ltd., Tel Aviv, Israel) devices, which consist of 6 LED lights that activate and deactivate upon touch. Three trials were performed using the upper limbs (right hand, left hand, and both hands) and three trials using the lower limbs (right foot, left foot, and both feet). The lights were arranged in a semicircle with a radius of 30 cm, with 15 cm spacing between them. Each trial lasted 30 s, and participants were instructed to touch as many lights as possible during the allotted time. No feedback or encouragement was provided during the trials. For the tasks performed with the hands, participants were seated, and the lights were arranged on a table according to the specified structure. The chair height was adjusted so that the arm formed a 90-degree angle with the work surface, and all the lights were reachable without moving the torso. For the tasks performed with the feet, participants were also seated, and the lights were arranged on the floor in the same structure. The seated position was chosen to minimize the influence of balance and postural control, isolating the visuomotor response. The chair height was adjusted so that the leg and thigh formed a 90-degree angle. The average reaction time was calculated for each trial, defined as the time between the appearance of the light stimulus and the participant's response.

No predefined reaction time window was imposed: each light stimulus remained illuminated until the participant responded by touching it. No exclusion criteria or cutoff mechanisms were applied for delayed responses;

all valid interactions were recorded and used to compute mean VMRT.

BlazePod® has been used in previous studies and demonstrated good test-retest reliability, intraclass correlation coefficients (ICCs) for both upper- and lower-limb response times ranging from 0.87 to 0.94 depending on the task [22].

Intervention

The intervention lasted for 8 weeks and has been delivered by two football coaches with a master's degree in kinesiology, with sessions held twice a week, each lasting 20 min. The visual training protocol was performed before each football training session. Each session consisted of five visual-cognitive exercises structured with alternating 40-second work intervals and 20-second rest intervals. The training was periodized into 4 microcycles of 2 weeks each, ensuring gradual progression in visual stimuli to optimize training effectiveness. Alongside the standard materials used during football training, the Sport Visual Training Academy training kit premium (SVTA method©, Carmagnola, Italy), and BlazePod® devices, were incorporated. The exercises focused on rapid and accurate execution of visual tasks from the SVTA protocol, with minimal motor involvement. The protocol was designed to maintain engagement and ensure sustained visual performance without inducing physical fatigue. While the general structure remained consistent (5 exercises per session, 40:20 work–rest ratio), specific tasks were adapted weekly to introduce new perceptual challenges, technical variations, and environmental constraints (e.g., adding obstacles, dual-task elements, or requiring selective responses to specific stimuli). This progression aimed to enhance learning through systematic increases in cognitive and motor demands. A detailed description of the intervention is provided in supplementary material S1.

Table 1 Baseline participants characteristic

Characteristic	*N* = 35[1]
Cover Test (40 cm)	
Esophoria	1 (3%)
Exophoria	1 (3%)
Orthophoria	33 (94%)
Cover Test (6 m)	
Esophoria	12 (33%)
Exophoria	1 (3%)
Orthophoria	22 (64%)
Stereopsis	
80″	33 (94%)
110″	2 (5.7%)
Convergence	7.54 (2.35)
Ocular motility	
Normal	33 (94%)
Nystagmus in lateral gaze	2 (6%)
Eye Dominance (Left)	7 (20%)
Manual Dominance (Left)	4 (11%)
Podalic Dominance (Left)	4 (11%)

[1]n (%); Mean (SD)

Statistical analysis

Descriptive data are presented as mean ± standard deviation. A priori power analysis was conducted using G*Power 3.1.9.7 to estimate the minimum required sample size. The analysis assumed a medium effect size (Cohen's f = 0.30), an alpha level of 0.05, a desired power (1–β) of 0.80, and a moderate correlation between repeated measures ($r = 0.3$). Based on these parameters, the estimated sample size was 28 participants.

The distribution of the VMRT data has been explored trough the Shapiro-Wilk Test. To assess the effects of the intervention on VMRT and oculomotor performance, generalized linear mixed models (GLMMs) and cumulative link models (CLMMs/CLMs) were used for the analysis. Six GLMMs were fitted using the *glmer* function from the *lme4* package in R. Each model included a fixed effect for time (pre- vs. post-intervention) and a random intercept for ID, a unique identifier for each participant, to account for repeated measures. A Gamma distribution with a log-link function was specified to appropriately model the positively skewed data. For the ordinal outcomes related to oculomotor performance, four additional models were fitted using the *clmm* function from the *ordinal* package in R. These models included CLMMs with a random intercept for ID. All models included time (pre- vs. post-intervention) as a fixed effect. Effect sizes for the within-subject comparisons between pre- and post-intervention measurements were calculated using Cohen's d. Effect sizes were interpreted according to standard guidelines, with small, medium, and large effects defined as Cohen's d values of 0.2, 0.5, and 0.8, respectively. Due to the high number of significance test, the *p*-values of the models were adjusted according to Benjamini-Hockberg and statistical significance was considered for $p < 0.05$. Statistics was performed with R statistical package (R Core Team (2023). _R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria).

Results

36 participants were enrolled in the study; one was excluded due to stereopsis higher than 120“ (225”). Characteristics of the 35 participants are presented in Table 1.

The participants included in the study exhibited normal visual abilities. Specifically, 33 players showed orthophoria on the distance cover test, while two demonstrated esophoria. On the near cover test, 22 participants exhibited orthophoria, whereas 13 had esophoria.

Table 2 Parameter estimates from 6 generalized linear mixed models (GLMM) testing the effect of time on visuomotor reaction time across different tasks. Estimates are reported with standard errors (SE), test statistics, 95% confidence intervals (CI), and *p*-values

Dependent Variable	Pre Mean (SD)	Post Mean (SD)	Estimate	SE	Statistic	95% CI		*p*-value
Right Hand	530.83 (89.64)	455.06 (44.63)	-0.149	0.024	-6.119	[-0.196,	-0.101]	< 0.001
Left Hand	541.69 (74.43)	470.71 (42.05)	-0.137	0.020	-6.720	[-0.176,	-0.097]	< 0.001
Both Hands	522.34 (84.43)	466.46 (46.01)	-0.107	0.021	-5.214	[-0.148,	-0.067]	< 0.001
Right Foot	763.4 (179.25)	718.43 (93.42)	-0.049	0.028	-1.749	[-0.103,	0.006]	0.089
Left Foot	834.71 (180.77)	782.23 (136.58)	-0.058	0.028	-2.072	[-0.113,	-0.003]	0.054
Both Feet	755.71 (196.83)	701.97 (93.97)	-0.056	0.029	-1.934	[-0.112,	0.001]	0.066

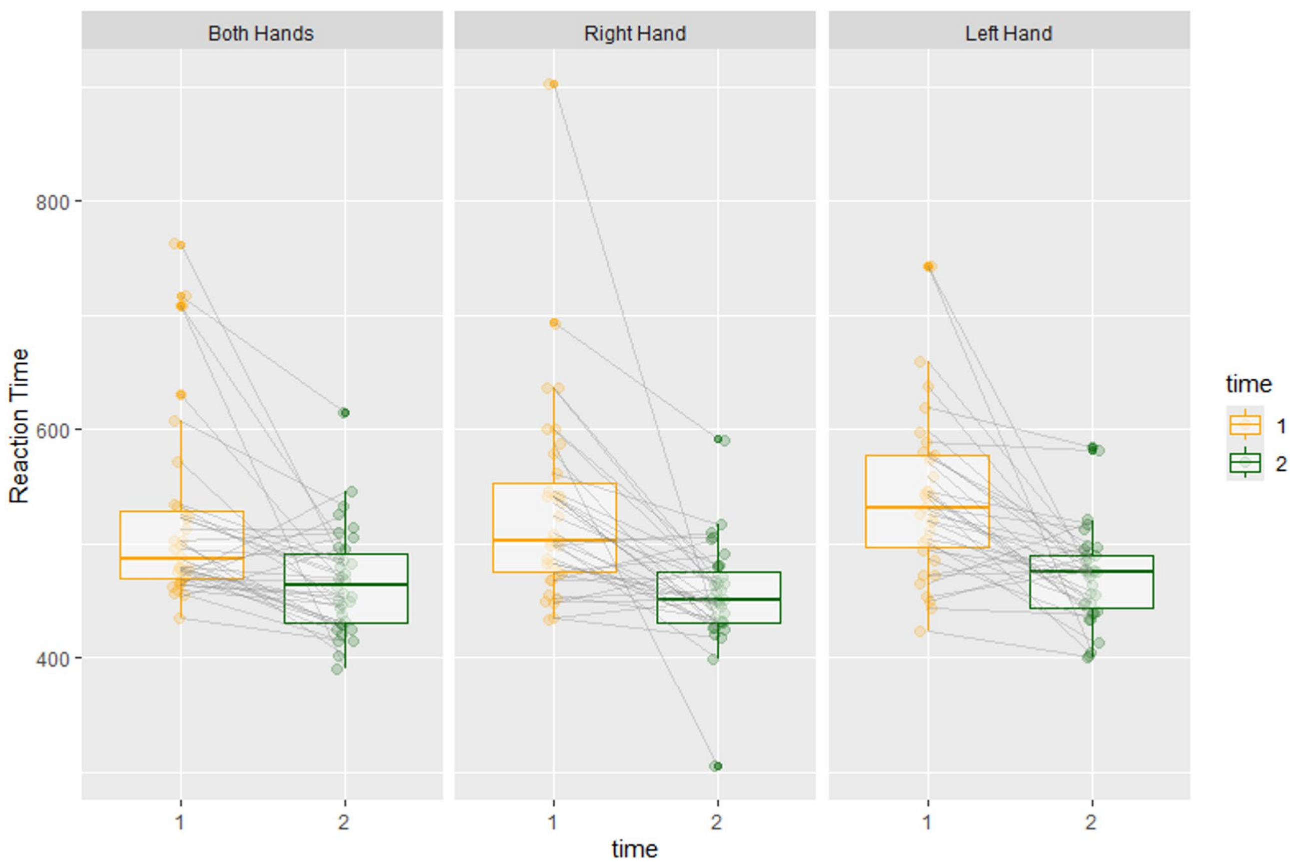

Fig. 1 Visuomotor reaction time before and after intervention for tasks performed with the hands

Stereopsis was measured at 80” for 33 players, while two showed a stereopsis of 110”. Additionally, two participants displayed nystagmus during lateral gaze. The mean convergence was 7.54 ± 2.35. Players demonstrated a significant reduction in VMRT following the intervention, particularly for tasks completed with the right hand (ß=-0.15; $p < 0.001$), left hand (ß= -0.14; $p < 0.001$), and both hands (ß= -0.11; $p < 0.001$). In contrast, no statistically significant reduction in VMRT was observed for tasks performed with the right foot (ß= -0.05; $p = 0.09$), left foot (ß= -0.06; $p = 0.05$), or both feet (ß= -0.06; $p = 0.07$) (**see** Table 2). Graphical representation of the results is reported inf Figs. 1 and 2. A statistically significant improvement was observed in the NSUCO test scores, specifically in the precision of saccadic movements (ß= 2.11; $p = 0.02$) and in body and head movement during saccadic tasks (ß= 0.11; $p < 0.001$). However, no significant changes were detected in the precision of pursuit movements (ß= -0.62; $p = 0.37$) or in body and head movement during pursuit tasks (ß= 0.83; $p = 0.21$) (**see** Table 3).

Discussion

The aim of the present study was to evaluate the effectiveness of an 8-week football-specific SVT program in improving VMRT and oculomotor function in recreational young football players. The intervention was

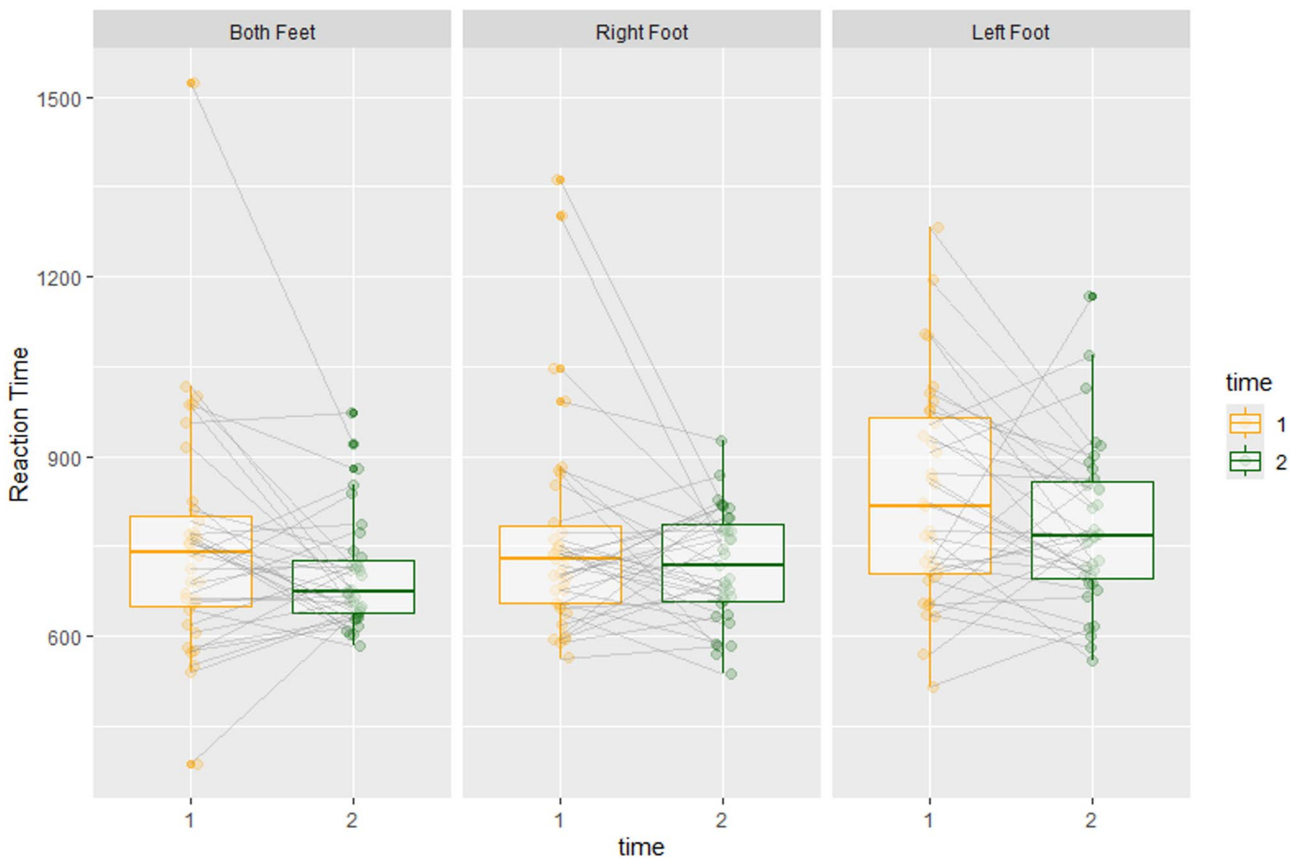

Fig. 2 Visuomotor reaction time before and after the intervention for tasks completed with the feet

Table 3 Parameter estimates from 4 cumulative link mixed models (CLMM) testing the effect of time on saccadic and pursuit movements. Estimates are reported with standard errors (SE), test statistics, 95% confidence intervals (CI), and *p*-values

Dependent Variable	Estimate	SE	statistic	95% CI	*p*.value
Saccadic					
Precision	0.100	0.017	5.865	[0.067, 0.134]	< 0.001
Head Movement	0.079	0.018	4.416	[0.044, 0.114]	< 0.001
Pursuit					
Precision	-0.027	0.017	-1.616	[-0.061, 0.006]	0.106
Head Movement	0.031	0.011	2.884	[0.010, 0.053]	0.004

associated with a reduction in reaction time during tasks performed with the upper limbs.

These findings align with previous evidence suggesting that the specificity of training is a key determinant of effectiveness. Abernethy and Wood, for instance, found that generalized visual training did not yield significant improvements in reaction time among a college-aged population [3]. Their results emphasize the limitations of non-specific approaches, which tend to target basic visual functions that are not typically the limiting factors for athletic performance [23, 24]. In contrast, our study implemented a sport-specific visual training protocol designed to reflect the visuomotor demands of football, thereby addressing the need for interventions with greater ecological validity.

The introduction of a sport-specific SVT program, incorporating visual stimuli presented in rapid sequences, may have contributed to the observed improvement in VMRT. Similar results were reported by Zwierko et al. in youth volleyball players who underwent a 6-week stroboscopic training program, which resulted in a substantial reduction in reaction time (effect size d = 0.87) [9]. This partially aligns with the effect size observed in the present study for the double-upper-limb VMRT task (d = 0.67).

Although the present study did not directly measure pre-motor and motor components of reaction time, it is possible that the observed improvements may, at least in part, reflect earlier stages of visuomotor processing (e.g., stimulus detection or decision-making). This interpretation is consistent with findings from Hülsdünker et al., who reported a moderate reduction in pre-motor time (d = 0.62) after a 10-week stroboscopic training program, without changes in motor time [8]. While their protocol and outcome measures differ from ours, their results suggest that visual training may primarily influence pre-motor aspects of performance. However, this interpretation remains tentative and should be verified in future studies using electromyographic or neurophysiological methods. The significant improvement in NSUCO scores, particularly in the precision of saccadic movements, further indicates that changes in reaction time could be associated not only with motor execution but also with improved oculomotor control.

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In contrast, the present study did not identify a statistically significant reduction in VMRT during tasks performed with the lower limbs. This discrepancy between upper- and lower-limb-related VMRT could be attributed to the greater coordinative complexity of tasks involving the lower limbs, which may have diminished the effectiveness of the intervention. Future studies should consider extending the intervention duration and focusing exclusively on visuomotor tasks involving the lower limbs. The transferability of reaction time improvements from trained to untrained tasks remains controversial. While some studies report generalized benefits of SVT across different motor responses [25], others emphasize the specificity of training effects, suggesting that improvements may be limited to the exact stimuli and response modalities practiced [3]. Our finding of significant gains in upper-limb VMRT but not in lower-limb tasks supports this specific hypothesis [25]. Although visuomotor reaction time has been shown to improve progressively throughout childhood and early adolescence [26], the magnitude of such maturational effects over a short time frame (e.g., 8 weeks) is unlikely to account for the size of the changes observed in this study. Nevertheless, we cannot fully rule out the contribution of natural developmental progression, which should be controlled for future studies with age-matched control groups.

In addition, while the improvement in VMRT might partly reflect a learning effect, the interval between the pre- and post-test phases (8 weeks) makes it less likely that short-term retest learning fully accounts for the observed changes. Previous studies have indicated that residual improvements from repeated exposure typically dissipate within 1–2 weeks [27]. Nevertheless, we cannot entirely exclude the possibility that practice effects contributed to the results, particularly given the young age of the participants.

Recent research has shown that excessive physical or neuromuscular fatigue can negatively affect visual stimulus processing, motor response quality, and learning efficiency, especially in youth athletes [25]. For this reason, particular attention was given to the structure and intensity of the visual training protocol. Exercises were selected to prioritize visual-cognitive engagement while minimizing physical exertion, ensuring that attentional and perceptual capacities were preserved throughout each session. This design choice aimed to avoid fatigue-related interference with visuomotor learning, as emphasized in previous literature.

Strength and limitations of the study.

This study, to the best of our knowledge, was the first exploring the effectiveness on VMRT of a specific SVT program, that integrates SVTA methodology with interactive light training. Compared to other vision training approaches, such as stroboscopic training or laboratory-based interventions requiring specialized lighting environments, the protocol used in the present study offers a more accessible and cost-effective alternative. Stroboscopic methods, while promising, often involve high-cost equipment and require controlled ambient conditions that limit their feasibility in applied sport settings. In contrast, our protocol is designed for field-based implementation, using portable LED devices that can be easily integrated into regular team training sessions. However, this study presents several limitations. First, the absence of a control group does not allow to quantify the learning effect related to the repetition of the test, however it should be noted that pre-post-test was performed 8 weeks apart realistically excluding the occurrence of a learning effect. Future studies should incorporate a familiarization phase before baseline testing to exclude test-learning effects and include longer-term follow-up assessments to evaluate the retention and consolidation of training-induced improvements over time.

Second, the examination of oculo-motricity was performed trough the NSUCO test, a quali-quantitative method for the assessment of saccadic and pursuit movement. Finally, it is important to note that excessive physical exertion during SVT may impair stimulus processing and motor response quality, particularly in youth athletes. As shown by Zwierko et al. [28], neuromuscular fatigue can compromise motor performance and learning. To prevent such interference, the present protocol was intentionally designed to limit physical intensity and prioritize focused engagement with visual tasks. These tests rely on clinical observation and judgment, which can introduce variability and reduce inter-rater reliability. However, the evaluation was performed independently by two trained optometrists, and any disagreement properly discuss with a third specialist. Although optometric data were collected to verify eligibility, future studies may explore whether specific visual characteristics, such as stereopsis or convergence, modulate responsiveness to SVT protocols.

Third, the non-blind design of the study may have introduced placebo effects or expectancy bias at the participant level. Specifically, players were aware of participating in a training protocol intended to improve visual and reaction skills, which could have increased motivation, effort, or attention during both training and testing sessions, independently of the actual intervention effects.

Future studies could introduce device-based measures of oculomotor function like eye-tracking technologies to reduce inter-rater variability. In addition to predictive relationships, future research should also examine whether SVT produces functional transfer to sport-specific contexts. Functional assessments such as game-time decision-making, on-field reaction speed, or anticipatory behavior in match-like situations would clarify the practical impact of visual training on football performance. Beyond mean changes in VMRT, future research should also examine intra-individual variability in reaction times, as this may provide deeper insight into the stability of visuomotor performance and attentional regulation during high-speed decision-making tasks.

Conclusion

The proposed SVT program was associated with a reduction in VMRT for upper limb, an improvement in precision of saccadic movement and a reduction in body and head movement during both saccadic and pursuit movement. Non-significant reduction in VMRT for lower limb and in pursuit precision were observed. These findings are particularly relevant to sports coaches, as the proposed intervention represents a simple and cost-effective training method for enhancing VMRT.

Practical implications

- Sport-specific vision training programs were associated with reduced reaction time and enhanced oculomotor function in youth players.
- Cost-effective methods, such as SVTA panels and interactive light training, could be easily used in a sport context.
- Sport-specific vision training can be successfully implemented in large groups of young recreational athletes.

Abbreviations

NSUCO	Northeastern State University College of Optometry
SVT	Sport Vision Training
VMRT	Visuo-Motor Reaction Time
CLMMs	Cumulative link models
GLMMs	Generalized linear mixed models
NSUCO	Northeastern State University College of Optometry
SVT	Sport Vision Training
SVTA	Sport Visual Training Academy
VMRT	Visuomotor reaction time

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-025-01368-z.

Supplementary Material 1

Acknowledgements
Not applicable.

Author contributions
T.P.: Conceptualization, Methodology, Data Curation, Writing-Original Draft; V.Z.: Formal analysis, Data Curation, Validation, Writing- Review & Editing; A.B.: Methodology, Investigation, Writing-Review & Editing; S.M.: Methodology, Investigation, Writing-Review & Editing; A.R.: Formal analysis, Data Curation, Validation, Writing- Review & Editing; M.V.: Investigation; G.B.: Investigation; M.L.: Investigation; E.M.: Methodology, Validation, Visualization; G.G.: Methodology, Supervision, Visualization; G.M.: Project Administration, Supervision; S.M.: Conceptualization, Supervison, Writing-Original Draft.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability
Data are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethic Committee of Vasta Area Emilia Centro. Study Code 113-2023-Sper-UniFe. This Research was conducted according to the Helsinki Declaration. Informed consent was obtained from both minors and their guardians/parents.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 28 March 2025 / Accepted: 17 September 2025
Published online: 16 October 2025

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