Original Article

Visio-spatial intelligence skills in non-athletes versus amateur boxers

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ABSTRACT

Background: Visio-spatial intelligence (VSI) skills, including abilities such as spatial awareness, visual processing, and motor coordination, are crucial for athletic performance, particularly in combat sports such as boxing. Amateur boxers require efficient visio-spatial skills (VSS) to quickly process visual information, track opponents' movements, and execute precise techniques. However, the extent to which amateur boxing experience enhances VSS remains unclear. This study compared the VSI skills of amateur boxers to those of non-athletes.

Methods: This cross-sectional, observational study recruited amateur boxers and non-athletes in the King Cetshwayo District, KwaZulu-Natal, Republic of South Africa. Participants, aged 18 to 27 years, underwent a detailed optometric screening and VSS tests, including accommodation facility, saccadic eye movements, speed of recognition, hand-eye coordination, peripheral awareness, and visual memory.

Results: The study included 90 participants, consisting of 45 amateur boxers (28 [62%] men aged 18 to 25 years and 17 [38%] women aged 18 to 27 years) and 45 non-athletes (29 [64%] men aged 18 to 26 years and 16 [36%] women aged 18 to 27 years). The mean (standard deviation) age of the boxers was 20.7 (2.2) years, whereas the mean age of the non-athletes was 21.9 (2.4) years ($P < 0.05$). Amateur boxers were superior in VSS, with marked advantages in accommodation facility, saccadic eye movement, speed of recognition, peripheral awareness, and hand-eye coordination (all $P < 0.001$). However, no significant difference was found in visual memory ($P > 0.05$). The greatest difference was observed in speed of recognition (88% higher in boxers), and the least difference was observed in visual memory (4% higher in boxers).

Conclusions: VSS differ between amateur boxers and non-athletes, indicating the importance of these skills for athletic performance. These findings emphasize the potential advantages of boxing training in enhancing VSS, which could impact athletic training and performance-enhancement strategies. This underscores the value of integrating visio-spatial training into athletic programs. The observed superiority of boxers in specific VSS areas has broad implications for theories of sports vision, the selection of appropriate tests, and the development of sport-specific VSS testing protocols. Further longitudinal studies with larger sample sizes are required to verify these findings and assess changes in these skills over time.

KEYWORDS

boxings, saccadic eye movements, saccade, vision, athletic performances, visual processing, AI (artificial intelligence)

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INTRODUCTION

Vision is essential for human actions, aiding in interpreting situations, selecting responses, and executing action plans [1]. In sports, particularly those requiring precise movements such as hitting a baseball or executing a bicycle kick, vision provides critical spatial and temporal cues for optimal performance [2-4]. Beyond its sensory function, vision is essential in planning an effective response to stimuli [5].

Combat sports such as boxing, karate, taekwondo, and judo demand swift adaptation and response to an opponent's brisk movements, necessitating intense coordination and rapid decision-making for a competitive edge [6]. Success in these sports relies not only on physical attributes such as strength and speed, but also on the ability to anticipate and make split-second judgments [6]. For instance, boxing heavily relies on visual processing, spatial awareness, and coordinated motor skills for quick assessments and precise counterattacks [7]. Boxers must maintain constant vigilance, reacting swiftly to close-range movements and relying heavily on visual cues from opponents [8].

Visio-spatial Intelligence (VSI) skills are crucial in boxing, enabling athletes to process visual information, judge distances, understand spatial relationships, and coordinate movements effectively [8]. Visio-spatial skills (VSS) involve interpreting the physical world, recognizing objects, and understanding their spatial connections [9]. Despite the acknowledged importance of VSS in boxing [8], research gaps persist, particularly in understanding the specific VSS crucial for success in the sport. Although research has explored vision in boxing, primarily examining the effects of boxing on eye health and the prevalence of eye injuries among boxers, a significant knowledge gap exists regarding the VSI skills of amateur boxers [10-14].

Therefore, this study aimed to address this gap by comparing the VSI skills of amateur boxers and non-athletes, contributing valuable insights into the role of vision in combat sports performance.

METHODS

This cross-sectional, observational study compared VSI skills between amateur boxers and non-athletes from the King Cetshwayo District in KwaZulu-Natal, Republic of South Africa (RSA), recruiting eligible individuals between March 2024 and May 2024. The Institutional Review Board of the University of Zululand approved this study (UZ-REC 0691-008 PGM 2023/89). The study adhered to the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants.

A sample size calculation using Python and the StatsModels Library was conducted with a significance level of 0.05, an effect size of 0.6, and a statistical power of 0.8. These parameters were chosen to ensure robustness in detecting meaningful differences between groups, aligning with standard practices in statistical testing [15].

The study included amateur boxers with a minimum of 6 months of boxing training experience. Non-athletes were defined as individuals who had not participated in regular sports training for at least one year [16]. Participants were required to have normal vision or correction to 20/20 or better. Individuals with a history of neurological disorders or uncorrectable visual impairments were excluded. Those with prior experience in VSS testing and individuals who had exercised within 48 h before the testing sessions were also excluded.

All participants underwent a general optometric screening using Spectrum Eyecare software (Version 6.0.0, Digital Optometry, RSA, Republic of South Africa) to evaluate their visual abilities and ascertain their eligibility for the study. All included individuals underwent a detailed examination to verify the healthy status of ocular structures, as outlined elsewhere [17].

Visual acuity: The assessment measured the eyes' ability to resolve detail, with the standard for normal vision defined as 6/6 (meters) or 20/20 (feet) [18]. In this study, the Spectrum Eyecare software was calibrated for a room length of 3 m with optimal screen size and resolution to ensure precise testing conditions. Participants sat 3 m away from a screen displaying rows of letters of different sizes. Starting with the largest letters, they continued to smaller sizes until an error was noted. The results were then analyzed by an optometrist.

VSS test battery: The study used standardized testing procedures to minimize dietary influences and physical/psychological effects, scheduling sessions on weekday mornings between 07:00 and 12:00 h [16, 19]. Participants were tested in a quiet, well-lit room, after a 9 – 12 h fast [16, 19]. Each participant completed two trials, with the highest score recorded. The study used a battery of VSS tests to evaluate and compare the visual skills of amateur boxers and non-athletes, including accommodation facility, saccadic eye movements, speed of recognition, hand-eye coordination, peripheral awareness, and visual memory [16, 19, 20].

Accommodation facility: This indicates the eyes' ability to adjust focus between distant and near objects and was evaluated using the Hart Near Far Rock Test [4, 16, 20, 21]. The Hart Chart (Bernell Corp., Mishawaka, IN, USA) was placed on a wall at eye level 3 m away, while participants held another chart at arm's length [16, 19, 21]. They read the first letter of the first line from each chart in sequence for 30 s, with errors recorded [16, 19, 21, 22]. Final scores were determined by deducting errors from the total score [22].

Saccadic eye movements: The rapid, voluntary shifts of the eyes between fixation points were assessed using saccadic eye movement charts [16, 19, 23]. Participants stood 3 m away from a wall on which two charts were positioned, each with vertically arranged letters and spaced 1 m apart [16, 19, 22, 24]. Participants verbally identified the first letter from the left chart and quickly shifted their gaze to the right chart to identify its first letter, continuing this sequence for 30 s while keeping their heads stationary [16, 19, 22, 24]. The number of errors and total number of letters read were recorded [24]. Final scores were determined by deducting errors from the total score [22].

Speed of recognition: The ability to quickly recognize and respond to visual stimuli was assessed using the Evasion program on Batak Pro (Quotronics Limited, Horley, Surrey, United Kingdom) [16, 19, 22, 24, 25]. Participants stood in front of the Batak Pro device, which consists of randomly illuminated targets arranged in a grid [25]. During the test, 100 targets lit up randomly for 1 s each while a countdown from 100 to 0 was displayed on the timer [25]. Participants had to swiftly and accurately strike lit targets, avoiding penalties for hitting incorrect or flashing targets [25]. Scores ranged from 0 to 100 points [19, 22].

Hand-eye coordination: The ability to perform tasks by synchronizing the eyes and hands was assessed using the Tennis Ball Wall Test [16, 19, 26]. Participants stood 2 m away from a wall with a marked target area. They alternated throwing a tennis ball at the target with one hand and catching it with the other hand for 30 s [16, 24, 26]. Both hands were evaluated for accuracy and coordination [16, 22, 24, 26]. Scores ranged from 0 to 60 catches.

Peripheral awareness: The ability to detect and react to stimuli appearing randomly across a broad visual field was evaluated using the Accumulator program on Batak Pro [16, 19, 22, 24, 25]. Random targets appeared on the Batak Pro screen and remained lit until the participant struck them [25]. Each session lasted 60 s [22, 25], and scores ranged from 0 to 80 points.

Visual memory: The ability to retain and recall visual information was assessed using the Flash Memory program on Batak Pro [16, 19, 22, 24, 25]. During the test, six random targets were illuminated for a user-selected display time of 0.5 s after a "double beep" prompt [25]. Participants aimed to strike these targets in any order within five target frames [22, 25]. Scores ranged from 0 to 54 [19].

Scoring: Scores for accommodation facility and saccadic eye movements reflected the number of correctly read letters, with deductions for errors [22]. Hand-eye coordination scores were based on successful catches [16, 19, 22, 24, 25]. The Batak Pro automatically recorded scores for speed of recognition, peripheral awareness, and visual memory [22].

The Statistical Package for the Social Sciences (SPSS) for Windows, version 18.0 (SPSS Inc., Chicago, IL, USA) was used to analyze the data. The Shapiro–Wilk test was used to assess normality of data distribution. The study employed quantitative research techniques and pre-existing VSS evaluations. Data are summarized using descriptive statistics such as mean, standard deviation (SD), median, interquartile range (IQR), minimum, maximum, and percentage differences. Because the dependent variables were continuous and non-normally distributed, the Mann–Whitney U test, which compares ranks between groups instead of means, was used to compare the two independent amateur boxer and non-athlete groups. A rank-ordered analysis, which involves ranking the data to corroborate the Mann–Whitney U test results and determine superior VSS empirically, was also conducted. Statistical significance was set at $P \leq 0.05$.

RESULTS

The study included 90 participants, aged 18 to 27 years (57 [63%] men aged 18 to 26 years and 33 [37%] women aged 18 to 27 years). The study was composed of two groups: 45 amateur boxers (28 [62%] men aged 18 to 25 years and 17 [38%] women aged 18 to 27 years) and 45 non-athletes (29 [64%] men aged 18 to 26 years and 16 [36%] women aged 18 to 27 years). The mean (SD) age of the boxers was 20.7 (2.2) years, whereas the mean (SD) age of the non-athletes was 21.9 (2.4) years ($P = 0.012$). Table 1 summarizes the participants' demographic data.

Amateur boxers outperformed non-athletes in several VSI skills, including accommodation facility, saccadic eye movement, speed of recognition, peripheral awareness, and hand-eye coordination (all $P < 0.001$). However, there was no discernible difference in visual memory between the two groups ($P > 0.05$) (Table 2).

Table 1. Demographic characteristics of the amateur boxers and non-athletes

Variable	Amateur boxers (n = 45)			Non-athletes (n = 45)		
	Men	Women	*P*-value	Men	Women	*P*-value
Age (y), Mean ± SD	20.9 ± 2.1	20.4 ± 2.3	0.392	22.3 ± 2.2	21.3 ± 2.5	0.151
Sex, n (%)	28 (62)	17 (38)	**0.017**	29 (64)	16 (36)	**0.007**

Abbreviations: y, years; SD, standard deviation; n, number of participants. Note: *P*-values < 0.05 is shown in bold.

Table 2. Comparison of visio-spatial skills of amateur boxers and non-athletes

VSS	Amateur boxers (n = 45) Median (IQR) (Range)	Non-athletes (n = 45) Median (IQR) (Range)	Difference (%)	*P*-value
Accommodation facility	34 (5.0) (26 to 44)	28 (4.5) (18 to 33)	18	**< 0.001**
Saccadic eye movement	58 (14.0) (37 to 82)	33 (6.0) (16 to 40)	43	**< 0.001**
Speed of recognition	58 (21.0) (12 to 93)	13 (10.5) (0 to 27)	88	**< 0.001**
Peripheral awareness	66 (9.5) (50 to 78)	56 (5.0) (48 to 66)	15	**< 0.001**
Hand-eye coordination	24 (6.5) (12 to 33)	21(5.5) (6 to 26)	12	**< 0.001**
Visual memory	44 (7.5) (34 to 52)	46 (8.0) (31 to 53)	4	0.393

Abbreviations: VSS, visio-spatial skills; n, number of participants; %, percentage; IQR, Interquartile range; Range, range is expressed as minimum to maximum. Note: *P*-values < 0.05 are shown in bold.

The skills were ranked according to the percentage difference in performance between boxers and non-athletes, highlighting the most significant differences. Speed of recognition had the greatest gap (88%), followed by saccadic eye movement (43%), accommodation facility (18%), peripheral awareness (15%), and hand-eye coordination (12%). Visual memory had the least difference at 4% (Table 2).

DISCUSSION

This study investigated the differences in VSI skills between amateur boxers and non-athletes using a comprehensive battery of VSS tests, and amateur boxers demonstrated superior VSS compared to non-athletes across several measures.

First, our amateur boxers exhibited a notable 18% advantage in accommodation facility, consistent with the findings of Millard et al. [16] and Mathe et al. [19], in which athletes generally excelled in this skill. However, contrasting results from Omar et al. [4] suggest occasional superiority among non-athletes in accommodation. Furthermore, our amateur boxers showed a remarkable 43% advantage in saccadic eye movements. This finding aligns with previous observations by Millard et al. [16], Mathe et al. [19], Lenoir et al. [27], Ahmad Rudin & Sharipan [28], and Vicente et al. [29], underscoring that athletes typically exhibit faster eye movements than non-athletes. Conversely, Nascimento et al. [30] found no discernible differences between skeet shooters and non-athletes in this regard.

Concerning speed of recognition, amateur boxers in our study outperformed non-athletes by a substantial 88%. This enhancement is supported by research on rugby players [16] and in the findings of Mathe et al. [19], highlighting athletes' faster recognition abilities. However, as noted by Nascimento et al. [30], such advantages may not universally apply across all sports disciplines. Additionally, amateur boxers in our study displayed a significant 15% advantage over non-athletes in peripheral awareness. Similar enhancements in peripheral awareness have been noted by Millard et al. [16], Mathe et al. [19], and Muinos [31], indicating a consistent trend of heightened awareness among athletes. Nonetheless, Nascimento et al. [30] found no significant disparity in peripheral awareness between skeet shooters and non-athletes.

Our amateur boxers exhibited a 12% advantage over non-athletes in hand-eye coordination. This finding is supported by research from Millard et al. [16], Mathe et al. [19], and Nascimento et al. [30], which showed consistently superior coordination skills among athletes. These skills are honed through repetitive sports practices, contributing to athletes' proficiency despite varying results in other visio-spatial tests [19, 30, 32-35].

Interestingly, there was no significant difference in visual memory between amateur boxers and non-athletes. This finding aligns with studies by Millard et al. [16] and Mathe et al. [19], which similarly reported comparable visual memory capacities between athletes and non-athletes. In contrast, Nascimento et al. [30] found enhanced visual memory among skeet shooters, indicating variability across different sports disciplines [30].

Boxers, accustomed to swiftly shifting focus between opponent movements and their own positioning, have enhanced accommodation skills compared to that of non-athletes [36]. Their frequent need to track fast opponent movements contributes to superior saccadic eye movement capabilities [37]. The dynamic nature of boxing demands rapid recognition skills for split-second decisions during bouts [38, 39], bolstered by physiological factors such as high maximal oxygen consumption levels that support quick recovery and sustained performance [40]. Additionally, boxers' enhanced anaerobic capacity facilitates the explosive movements and rapid reactions that are crucial in matches [40]. Boxers' heightened peripheral awareness reflects their constant monitoring of surroundings and opponents, aiding in anticipating attacks beyond their direct line of sight [41]. In contrast, the dynamic and unpredictable nature of boxing may prioritize quick reactions over long-term visual memory of patterns, potentially explaining the lack of significant difference in visual memory between boxers and non-athletes [42]. Soccer players had shorter premotor times during visual reaction tasks, both central and peripheral, compared to nonathletes [43]. This indicates that athletes respond more quickly to stimuli presented in central and peripheral positions [43].

Our study hypothesized and confirmed that amateur boxers exhibit superior VSS compared to non-athletes. This highlights the substantial role of boxing training in enhancing the essential visual skills crucial for athletic performance. The study emphasizes the need to incorporate visio-spatial training into athletic programs to optimize performance, focusing on areas such as accommodation facility, saccadic eye movements, speed of recognition, peripheral awareness, and hand-eye coordination. The current study demonstrates several significant strengths. The study utilized a comprehensive battery of VSS tests to thoroughly assess the skills of amateur boxers. The findings reveal significant enhancements in these skills among amateur boxers, supported by statistically significant differences across multiple measures. References to previous research enhance credibility and contextualize the findings within the academic landscape, underscoring the critical role of VSS in sports performance, particularly in boxing. While providing valuable insights, the study featured limitations such as a small sample size and a focus only on amateur boxers and non-athletes, which may limit generalizability. Further research should consider larger and more diverse populations, including professional boxers and athletes from other sports, to better understand VSS across different athletic conditions. Longitudinal studies would be beneficial in tracking developmental trends of VSS over time. The application of artificial intelligence (AI) in sports training could further enhance skills by providing personalized training programs and real-time feedback [44]. Additionally, AI can offer instant analysis and feedback during training sessions, helping athletes make immediate adjustments to their technique [45-47]. Therefore, advanced technologies such as eye-tracking and AI-driven analysis could provide more accurate assessments and help to optimize individualized training protocols.

CONCLUSIONS

This study revealed significant disparities in VSI skills between amateur boxers and non-athletes. Regular boxing training correlated with superior performance in speed of recognition, saccadic eye movements, accommodation facility, hand-eye coordination, and peripheral awareness. These findings suggest that the rigorous visual and physical demands of boxing are likely to contribute to these specific cognitive enhancements. In clinical practice, insights from this study could inform the development of targeted rehabilitation programs for individuals with visio-spatial impairments, employing training methods akin to those used in boxing. However, the efficacy of this approach should be verified by further clinical trials. From a research perspective, this study emphasizes the importance of investigating sport-specific cognitive training to enhance VSS. Overall, structured physical training, such as boxing, has the potential to significantly improve cognitive functions related to VSI, with implications for both sports performance and clinical interventions. Further longitudinal studies with larger sample sizes are required to verify these findings and to assess changes in these skills over time.

ETHICAL DECLARATIONS

Ethical approval: The Institutional Review Board of the University of Zululand approved this study (UZ-REC 0691-008 PGM 2023/89). The study adhered to the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants.

Conflict of interest: None.

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REFERENCES

1. Örs BS, Cantas F, Onarici Gungor E, Simsek D. Assessment and Comparison of Visual Skills among Athletes. Spor Performans Arast Derg. 2019 Dec;10(3):231-41. doi: 10.17155/omuspd.522342.
2. Hayhoe MM. Vision and Action. Annu Rev Vis Sci. 2017 Sep 15;3:389-413. doi: 10.1146/annurev-vision-102016-061437. Epub 2017 Jul 17. PMID: 28715958.
3. Laby DM, Appelbaum LG. Review: Vision and On-field Performance: A Critical Review of Visual Assessment and Training Studies with Athletes. Optom Vis Sci. 2021 Jul 1;98(7):723-731. doi: 10.1097/OPX.0000000000001729. PMID: 34328451.
4. Omar R, Kuan YM, Zuhairi NA, Manan FA, Knight VF. Visual efficiency among teenaged athletes and non-athletes. Int J Ophthalmol. 2017 Sep 18;10(9):1460-1464. doi: 10.18240/ijo.2017.09.20. PMID: 28944208; PMCID: PMC5596234.
5. Du Toit PJ, Kruger PE, Mahomed AF, Kleynhans M, Jay-du Preez T, Govender C, Mercier J. The effect of sports vision exercises on the visual skills of university students science. African Journal for Physical Health Education, Recreation and Dance. 2011 Sep 1;17(3):429-40. doi: 10.10520/EJC19729.
6. Russo G, Ottoboni G. The perceptual–Cognitive skills of combat sports athletes: A systematic review. Psychology of Sport and Exercise. 2019 Sep 1;44:60-78. doi: 10.1016/j.psychsport.2019.05.004.
7. Yordanova Y, Pulev T, Kirilova K, Ruteva M, Stambolieva K. Sport experience and visual motor reaction time of boxers. Journal of Physical Education and Sport. 2023 May 1;23(5):1176-81. doi: 10.7752/jpes.2023.05146.
8. Lesiakowski P, Zwierko T, Krzepota J. Visuospatial attentional functioning in amateur boxers. Journal of Combat Sports & Martial Arts. 2013 Aug 1;4(2):141-4. doi: 10.5604/20815735.1090659.
9. Pal A, Biswas A, Pandit A, Roy A, Guin D, Gangopadhyay G, Senapati AK. Study of visuospatial skill in patients with dementia. Ann Indian Acad Neurol. 2016 Jan-Mar;19(1):83-8. doi: 10.4103/0972-2327.168636. PMID: 27011635; PMCID: PMC4782559.
10. Corrales G, Curreri A. Eye trauma in boxing. Clin Sports Med. 2009 Oct;28(4):591-607, vi. doi: 10.1016/j.csm.2009.07.004. PMID: 19819404.
11. Kagmeni G, Nguefack-Tsague G, Ebana Mvogo SR, Ebana Mvogo C. Ophthalmological findings in Cameroonian boxers. Clin Ophthalmol. 2017 Jun 12;11:1121-1126. doi: 10.2147/OPTH.S134173. PMID: 28652699; PMCID: PMC5476758.
12. Moosa M, Kaushik J, Singh A. Clinical evaluation of ophthalmic findings in active, amateur, adult, competitive male boxers in India. Rom J Ophthalmol. 2024 Jan-Mar;68(1):25-30. doi: 10.22336/rjo.2024.06. PMID: 38617717; PMCID: PMC11007561.
13. Chang CC, Saifee M, Ton L, Ashraf D, Winn BJ, Kersten R, Vagefi MR, Deiner M, Grob SR. Eye Trauma in Mixed Martial Arts and Boxing. Ophthalmic Plast Reconstr Surg. 2024 Jan-Feb 01;40(1):75-87. doi: 10.1097/IOP.0000000000002510. Epub 2023 Sep 1. PMID: 37656909; PMCID: PMC10926996.
14. Leong D, Morettin C, Messner LV, Steinmetz RJ, Pang Y, Galetta SL, Balcer LJ. Visual Structure and Function in Collision Sport Athletes. J Neuroophthalmol. 2018 Sep;38(3):285-291. doi: 10.1097/WNO.0000000000000572. PMID: 28885451.
15. Krzywinski M, Altman N. Points of significance: Power and sample size. Nature Methods. 2013 Dec 1;10(12):1139–1140. doi: 10.1038/nmeth.2738.
16. Millard L, Shaw I, Breukelman GJ, Shaw BS. Visio-spatial skills in athletes: comparison of rugby players and non-athletes. Sport Sciences for Health. 2021 Mar;17:137-43. doi: 10.1007/s11332-020-00663-1.
17. Wilkie DA. The Ophthalmic Examination as It Pertains to General Ocular Toxicology: Basic and Advanced Techniques and Species-Associated Findings. Ocular Pharmacology and Toxicology. 2013 Aug 29:143–203. doi: 10.1007/7653_2013_7. PMCID: PMC7122657.
18. Caltrider D, Gupta A, Tripathy K. Evaluation of Visual Acuity. 2024 May 1. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan–. PMID: 33231977.
19. Mathe N, Millard L, Breukelman GJ, Mathunjwa M. Differences in visio-spatial intelligence between non-athletes and netball players. Front Sports Act Living. 2023 Feb 20;5:1109967. doi: 10.3389/fspor.2023.1109967. PMID: 36891127; PMCID: PMC9986416.
20. Millard L, Shaw I, Breukelman GJ, Shaw BS. Differences in visio-spatial expertise between 1st division rugby players and non-athletes. Heliyon. 2021 Feb 16;7(2):e06290. doi: 10.1016/j.heliyon.2021.e06290. PMID: 33665445; PMCID: PMC7900701.
21. Vera J, Redondo B, Molina R, Koulieris GA, Jiménez R. Validation of an Objective Method for the Qualitative and Quantitative Assessment of Binocular Accommodative Facility. Curr Eye Res. 2020 May;45(5):636-644. doi: 10.1080/02713683.2019.1688837. Epub 2019 Nov 13. PMID: 31675903.
22. Shaw BS, Breukelman G, Millard L, Moran J, Sandercock G, Shaw I. Maximal aerobic exercise and acute visual performance in females: Implications for concussion side-line testing. J Optom. 2024 Oct-Dec;17(4):100515. doi: 10.1016/j.optom.2024.100515. Epub 2024 Mar 12. PMID: 38479117; PMCID: PMC11651031.
23. Imaoka Y, Flury A, de Bruin ED. Assessing Saccadic Eye Movements With Head-Mounted Display Virtual Reality Technology. Front Psychiatry. 2020 Sep 17;11:572938. doi: 10.3389/fpsyt.2020.572938. PMID: 33093838; PMCID: PMC7527608.
24. Shaw BS, Breukelman GJ, Millard L, Shaw I. Effect of a prolonged maximal bout of exercise on visual performance. Asian Journal of Sports Medicine. 2022 Mar 31;13(1):1-7. doi: 10.5812/asjsm.119406.
25. Vater C, Strasburger H. Topical Review: The Top Five Peripheral Vision Tools in Sport. Optom Vis Sci. 2021 Jul 1;98(7):704-722. doi: 10.1097/OPX.0000000000001732. PMID: 34285176.
26. Szabo DA, Neagu N, Teodorescu S, Sopa IS. Eye-hand relationship of proprioceptive motor control and coordination in children 10–11 years old. Health, Sports & Rehabilitation Medicine. 2020 Sep;21(3):185-91. doi: 10.26659/pm3.2020.21.3.185.
27. Lenoir M, Crevits L, Goethals M, Duyck P, Wildenbeest J, Musch E. Saccadic eye movements and finger reaction times of table tennis players of different levels. Neuro-ophthalmology. 2000 Jan 1;24(2):335-8. doi: 10.1076/noph.24.2.335.7153.

28. Ahmad Rudin AM, Sharipan MN. Improvement of the saccadic eye movements with the sport training activity. InProceedings of the 2nd International Colloquium on Sports Science, Exercise, Engineering and Technology 2015 (ICoSSEET 2015) 2016 (pp. 261-268). Springer Singapore. doi:10.1007/978-981-287-691-1_28.
29. Vicente R, Bittencourt J, Costa É, Nicoliche E, Gongora M, Di Giacomo J, Bastos VH, Teixeira S, Orsini M, Budde H, Cagy M, Velasques B, Ribeiro P. Differences between hemispheres and in saccade latency regarding volleyball athletes and non-athletes during saccadic eye movements: an analysis using EEG. Arq Neuropsiquiatr. 2023 Oct;81(10):876-882. doi: 10.1055/s-0043-1772830. Epub 2023 Oct 18. PMID: 37852289; PMCID: PMC10631850.
30. Nascimento H, Alvarez-Peregrina C, Martinez-Perez C, Sánchez-Tena MÁ. Differences in Visuospatial Expertise between Skeet Shooting Athletes and Non-Athletes. Int J Environ Res Public Health. 2021 Jul 31;18(15):8147. doi: 10.3390/ijerph18158147. PMID: 34360440; PMCID: PMC8346005.
31. Z Muiños M, Ballesteros S. Peripheral vision and perceptual asymmetries in young and older martial arts athletes and nonathletes. Atten Percept Psychophys. 2014 Nov;76(8):2465-76. doi: 10.3758/s13414-014-0719-y. PMID: 25005071.
32. Bhukar JP. Effect of six week coordinative drills on eye hand coordination of young Athletes. International Journal of Physiology, Nutrition and Physical Education 2023; 8(1): 75-78. doi: 10.22271/journalofsport.2023.v8.i1b.2672.
33. Kaluga E, Straburzynska-Lupa A, Rostkowska E. Hand-eye coordination, movement reaction time and hand tactile sensitivity depending on the practiced sports discipline. J Sports Med Phys Fitness. 2020 Jan;60(1):17-25. doi: 10.23736/S0022-4707.19.09726-3. Epub 2019 Oct 16. PMID: 31640309.
34. Mohammadi N, Rostami R, Alborzi M. Visual skills of the female athletes in team and individual sports. Annals of Applied Sport Science. 2016 Dec 10;4(4):69-77. doi: 10.18869/acadpub.aassjournal.4.4.69.
35. Irem S, Mohammad N. Comparative study of eye–hand coordination among volleyball playing and nonvolleyball playing university students. Saudi Journal of Sports Medicine. 2020 Sep 1;20(3):64-9. doi: 10.4103/sjsm.sjsm_32_20.
36. Hausegger T, Vater C, Hossner EJ. Peripheral Vision in Martial Arts Experts: The Cost-Dependent Anchoring of Gaze. J Sport Exerc Psychol. 2019 Jun 1;41(3):137-145. doi: 10.1123/jsep.2018-0091. Epub 2019 Jun 2. PMID: 31156024.
37. Limballe A, Kulpa R, Vu A, Mavromatis M, Bennett SJ. Virtual reality boxing: Gaze-contingent manipulation of stimulus properties using blur. Front Psychol. 2022 Sep 29;13:902043. doi: 10.3389/fpsyg.2022.902043. PMID: 36248589; PMCID: PMC9557204.
38. Ottoboni G, Russo G, Tessari A. What boxing-related stimuli reveal about response behaviour. J Sports Sci. 2015;33(10):1019-27. doi: 10.1080/02640414.2014.977939. Epub 2014 Nov 11. PMID: 25385452.
39. Hukkanen E, Häkkinen K. Effects of Sparring Load on Reaction Speed and Punch Force During the Precompetition and Competition Periods in Boxing. J Strength Cond Res. 2017 Jun;31(6):1563-1568. doi: 10.1519/JSC.0000000000001885. PMID: 28538306.
40. Chaabène H, Tabben M, Mkaouer B, Franchini E, Negra Y, Hammami M, Amara S, Chaabène RB, Hachana Y. Amateur boxing: physical and physiological attributes. Sports Med. 2015 Mar;45(3):337-52. doi: 10.1007/s40279-014-0274-7. PMID: 25358529.
41. Vater C, Kredel R, Hossner EJ. Examining the functionality of peripheral vision: From fundamental understandings to applied sport science. Current Issues in Sport Science. 2017;2:1-11. doi: 10.36950/2017ciss010.
42. Kibele A. Non-consciously controlled decision making for fast motor reactions in sports—A priming approach for motor responses to non-consciously perceived movement features. Psychology of Sport and Exercise. 2006 Nov 1;7(6):591-610. do:10.1016/j.psychsport.2006.05.001.
43. Ando S, Kida N, Oda S. Central and peripheral visual reaction time of soccer players and nonathletes. Percept Mot Skills. 2001 Jun;92(3 Pt 1):786-94. doi: 10.2466/pms.2001.92.3.786. PMID: 11453206.
44. Musat CL, Mereuta C, Nechita A, Tutunaru D, Voipan AE, Voipan D, Mereuta E, Gurau TV, Gurău G, Nechita LC. Diagnostic Applications of AI in Sports: A Comprehensive Review of Injury Risk Prediction Methods. Diagnostics (Basel). 2024 Nov 10;14(22):2516. doi: 10.3390/diagnostics14222516. PMID: 39594182; PMCID: PMC11592714.
45. Novatchkov H, Baca A. Artificial intelligence in sports on the example of weight training. J Sports Sci Med. 2013 Mar 1;12(1):27-37. PMID: 24149722; PMCID: PMC3761781.
46. Mateus N, Abade E, Coutinho D, Gómez MÁ, Peñas CL, Sampaio J. Empowering the Sports Scientist with Artificial Intelligence in Training, Performance, and Health Management. Sensors (Basel). 2024 Dec 29;25(1):139. doi: 10.3390/s25010139. PMID: 39796930; PMCID: PMC11723022.
47. Dijkhuis TB, Blaauw FJ, van Ittersum MW, Velthuijsen H, Aiello M. Personalized Physical Activity Coaching: A Machine Learning Approach. Sensors (Basel). 2018 Feb 19;18(2):623. doi: 10.3390/s18020623. PMID: 29463052; PMCID: PMC5856112.