

Differences in visual skills between trap and pistol shooters across shooting modality, performance level, and sex

DANIEL MON-LÓPEZ¹; GÜLÇİN GÜLER²; JEFFERSON RUEDA ROSALES³; RICARDO BERNARDEZ-VILABOA⁴; MANUEL SILLERO-QUINTANA^{5*}; JORGE GARCÍA-GONZÁLEZ⁶.

^{1,5}Facultad de Ciencias de la Actividad Física y del Deporte (INEF). Sports Department. Universidad Politécnica de Madrid, 28040 Madrid, SPAIN;

² Department of Physical Education and Sports, Eskişehir Technical University, Eskişehir, TURKEY;

³Departamento de Ciencias Humanas y Sociales, Universidad de las Fuerzas Armadas-ESPE;

⁴ Department of Optometry and Vision, Faculty of Optics and Optometry, Universidad Complutense de Madrid; 28037 Madrid, SPAIN;

⁶ Facultad de Ciencias de la Actividad Física y del Deporte (INEF). Department of Social Sciences. Universidad Politécnica de Madrid, Madrid, Spain. 28040 Madrid, SPAIN

Published online: September 30, 2026

Accepted for publication: September 15, 2026

DOI:10.7752/jpes.2026.09169

Abstract

Vision plays a critical role in shooting sports, where even minor visual deficiencies can compromise athletic performance. Because pistol and trap shooting involve vastly different technical demands, identifying discipline-specific visual profiles is essential for optimizing athletic preparation. This study evaluated visual capabilities across shooting modalities (trap vs. pistol), competitive performance levels (elite vs. non-elite), and sexes (male vs. female). A sample of 122 national-level shooters (69 trap, 53 pistol; 33 elite, 89 non-elite; 28 women, 94 men) completed a comprehensive battery of optometric assessments under photopic conditions. Assessments included binocular visual acuity (BVA), depth perception stereopsis (Howard-Dolman), binocular accommodation facility (BAF), and central, peripheral, and total visual recognition time (VRT). Group differences were evaluated using independent t-tests and two-way ANCOVAs with age as a covariate. Pistol shooters demonstrated superior central, peripheral, and total VRT, alongside better maximum stereopsis thresholds, whereas trap shooters achieved significantly higher BVA. Elite athletes outperformed non-elite shooters in BVA, BAF, central VRT, and total VRT. Age-adjusted ANCOVAs revealed a significant sex-by-level interaction for BVA, where elite females performed better than non-elite females, and non-elite males outperformed non-elite females. Additionally, elite trap shooters exhibited higher BAF and central VRT compared to their non-elite counterparts, and non-elite pistol shooters displayed faster VRT than non-elite trap shooters. In conclusion, trap and pistol shooting rely on distinct visual skill profiles shaped by specific task demands. Elite shooters consistently exhibit superior visual acuity, accommodative flexibility, and visual recognition speed compared to non-elite athletes. Coaches and optometrists should implement discipline-specific visual examinations and tailored vision training programs to enhance perceptual-motor efficiency and competitive outcomes in Olympic shooting.

Key Words: Stereopsis, Depth perception, Accommodative facility, Perceptual speed, Athletic expertise

Introduction

Sports vision is an emerging subfield within optometry that focuses on enhancing and maintaining visual capabilities to optimize athletic performance (Nascimento, Martinez-Perez et al., 2021). Although vision is essential for success in most sports (Laby & Appelbaum, 2021), it is particularly critical in Olympic shooting, where even minimal visual errors can lead to a decrease in performance (Mon-López et al., 2022a).

Olympic shooting consists of four main disciplines: Running target, pistol, rifle, and shotgun. Pistol and rifle events are divided into two categories: air and firearm, while the shotgun includes two modalities: skeet and trap (ISSF, 2025). Trap shooting requires athletes to hit targets moving away from or across them at speeds of up to 100 km·h⁻¹, whereas pistol shooting involves aiming at a stationary target (Causer et al., 2010). These technical distinctions correspond to different visual demands and movement dynamics, as suggested by Erickson's visual classification, in which pistol shooting is considered as static and trap shooting as non-static. (Erickson, 2020)

In trap shooting, athletes must visually track and intercept fast-moving clay targets, coordinating a rapid sequence of actions such as aiming, moving, firing, and following through (Guo et al., 2024a), in contrast, pistol shooting is self-paced and involves a fixed target, requiring exceptional precision and fine motor control; notably, the 10-point scoring zone measures only 11.5 ± 0.1 mm (ISSF, 2025). Considering these differences in target vision, visual skills could be considered as critical determinants of performance in both disciplines (Mon-

López et al., 2022a). Consequently, conducting a detailed analysis of the visual requirements and task characteristics of each event may help identify which perceptual factors are most relevant to optimizing performance (Erickson, 2018), as different visual skills appear to be essential for success given the distinct movement dynamics across shooting disciplines (Laby & Appelbaum, 2021).

Regarding vision, gaze behavior, including saccades, fixations, and the quiet eye (QE), has been the focus of previous studies (Causer et al., 2010; Di Russo et al., 2003; Güler et al., 2024; Shah et al., 2020). Additionally, visual acuity, stereopsis, accommodation, convergence ability, multiple object tracking, and precision ocular motility are among the visual and perceptual skills considered important in sports (Erickson, 2020). However, visual skills in Olympic shooting have received limited academic attention (Garaszczuk et al., 2025a; Mon-López et al., 2022a).

Visual acuity is the ability of the visual system to resolve fine spatial details (Zimmerman et al., 2011), being a key component of visual assessment in athletes and influencing related visual skills such as dynamic visual acuity, depth perception, and accommodation accuracy that affect multiple aspects of visual performance (Erickson, 2021). Enhanced visual acuity and depth perception enable athletes to identify targets and allow them to estimate distances with greater precision (Rienhoff et al., 2016). Specifically, in aiming/target sports, visual acuity seems to play a particularly critical role showing expert athletes superior visual acuity compared to non-elite athletes or the general population (Gao et al., 2015; Laby et al., 1996; Uchida et al., 2013). Similarly, Garaszczuk et al. have recently reported that national-level shooters exhibited better visual acuity than the control group, despite being older. (Garaszczuk et al., 2025a)

In addition to visual acuity, stereopsis is a key binocular function that allows athletes to accurately perceive depth and spatial relationships (Rodrigues, 2020). Stereopsis is an important visual skill required for daily activities, and its impairment negatively affects interactions with both people and objects (O'Connor & Tidbury, 2018), but this skill is crucial in sports, as it supports accurate perception of object speed and position (Rodrigues, 2020). However, the extent to which stereopsis contributes to performance varies between disciplines. In some sports, its role is predominant, whereas in others it is less influential or functions as a complementary ability alongside other visual and non-visual skills (Presta et al., 2021). Dynamic stereopsis is primarily involved when tracking moving targets, while static stereopsis (i.e. the perception of depth in stationary objects) is particularly relevant in precision sports such as golf or archery, where the target remains fixed (Boden et al., 2009). Another critical component of visual performance is accommodation. The visual process that allows athletes to maintain clear vision when shifting focus between different distances. Strong and flexible focusing ability supports stable visual information (Rodrigues, 2020). The importance of accommodative facility in shooting has been particularly emphasized (Mon-López et al., 2022a). For example, air pistol shooters must focus on the front sight, avoid looking directly at the target, and perceive the target as slightly blurred (Reinkemeier & Bühlmann, 2013). This ability allows the shooter to maintain optimal focus across varying distances, making it an essential visual skill (Mon-López et al., 2022a). Accommodation plays such a crucial role in the act of aiming that even some non-presbyopic shooters are recommended to use a small near correction to support their accommodative response (Garaszczuk et al., 2025b).

In addition to these static and dynamic visual functions, cognitive-perceptual skills, such as visual recognition, play a crucial role in athletic success by enabling quick and accurate decision making in dynamic environments (Rodrigues, 2020). Visual recognition can be trained and assessed using a tachistoscope, which serves as a tool to improve perceptual speed (J. Clark et al., 2020) and as an instrument to measure inspection or recognition time (Reichow et al., 2011). Several studies have shown that expert athletes can process and evaluate visual information more rapidly than less-experienced athletes (Burris et al., 2018; Reichow et al., 2011), although, others have found no significant differences between athletes and non-athletes in visual recognition performance (Gao et al., 2015; Nascimento, Martinez-Perez, et al., 2021). Consequently, existing evidence remains inconclusive and, to date, no study has examined these visual-perceptual variables comparing air pistol and trap shooters.

Successful performance often relies on the ability to process visual cues and execute the corresponding motor response (Erickson, 2021). The literature indicates that elite athletes outperform non-athletes and lower-level athletes in visual, perceptual, cognitive, and motor skills (Gao et al., 2015; Rodrigues, 2020). Different studies have shown that they possess superior ability to detect perceptual cues, executing efficient eye movements, and demonstrate faster processing speed and greater attentional control (Gao et al., 2015; Mann et al., 2007). Within shooting sports, the literature indicates that elite pistol shooters have different visual skills compared to novices (Mon-López et al., 2022a). However, it remains unclear whether and how these visual skills differ between shooting disciplines.

Although research on gaze behavior in Olympic shooting has been growing, significant gaps remain, particularly with respect to detailed examination of specific visual skills (Mon-López et al., 2022a). Furthermore, visual skills associated with successful performance have not yet been definitively determined (Erickson, 2021). Considering the fundamental role of vision in this sport, the present study aims to examine visual skills (binocular visual acuity, binocular accommodative facility, stereopsis, and visual perception) of shooters in shooting modalities (trap and pistol), competitive levels (elite and non-elite), and sexes (male and female).

Material and Methods

Participants

A total of 122 national-level shooters participated in the study, of whom, 69 were trap shooters, five women ($M = 23.20 \pm 7.05$) and 64 men ($M = 35.80 \pm 14.08$) years old and 53 were pistol shooters, 23 women ($M = 31.09 \pm 14.01$) and 30 men ($M = 42.87 \pm 17.82$) years old. As inclusion criteria, all shooters were required to have participated in at least one national championship prior to the data collection period and to have a minimum of one year of shooting experience. Additionally, all shooters who had visual impairments or injuries that could have affected their performance were excluded from the study. The descriptive and distribution data for the shooters are presented in Table 1.

All participants were informed of the objectives, protocols, and risks of the study procedures before signing a consent form. This study was approved by the University Ethics Committee (no. FDRED00000-DML-DATOS-20230609).

Task and procedure

Data collection was carried out in the same month (October) during the National Championship of both events (pistol and trap). Data collection was carried out by the same trained researchers and was supervised by a Ph.D. optometry expert.

Before data collection on visual skills, all participants completed a questionnaire with their demographic values (see variables section). Finally, sport performance was obtained from the official results of the competition given by the competition referees according to the ISSF rules. (ISSF, 2025)

Data collection was carried out indoors in a room with photopic lighting conditions, where auditory and visual disturbances could be controlled and minimized. The total data collection protocol lasted more than 20 minutes for each shooter, before starting the warm-up, while they were comfortably seated and using their normal sport visual correction. The order of the visual test for each participant was randomly assigned to avoid possible bias.

The binocular visual acuity (BVA) test was carried out using a Sloan letter chart (ETDRS, Precision Vision, USA) at a 4 m distance with letter optotype cardboard and photopic lighting, registering the visual acuity line in which 60% of the letters can be distinguished binocularly. Those athletes with visual acuity values less than 0.8 were excluded from the study similarly to Mon-Lopez et al. (Mon-López et al., 2022b)

The binocular accommodation facility was measured in cycles per minute using a ± 2 D flipper with a 40 cm optotype. The protocol consists of changing from positive to negative lenses and vice versa, focusing the 0.8 (decimal) visual acuity line for one minute. Furthermore, the same protocol was repeated to test the monocular accommodation facility in the director eye (Mon-López et al., 2022a).

Stereopsis was tested using the Howard-Dolman instrument (MedEnvoy Global, The Netherlands), which consists of a black box with a perforated window (20 x 12 cm). The athlete can see two vertical rods (0.8 cm diameter) through the window, one stationary, and the other can be moved forward and backwards with a string. The athletes were placed three meters from the apparatus with their eyes perpendicularly aligned. The purpose of the test was to align the two sticks at the same distance. The positive or negative difference between the sticks was noted in cm, representing the best stereopsis or depth perception when the result was zero or very close to it (Lord & Dayhew, 2001). The test was repeated three times after two rehearsal times to get used to the instrument. The average of the three measurements was considered as the final result.

The tachistoscope test was used to check visual perception speed and memory using numbers and letters (Clark et al., 2012). It was measured on a 50 cm laptop with a presentation generated in Superlab Software (Cedrus, USA). A sequence of four to six digits (numbers and capital letters) was presented with different exhibition times on 50 screens, 25 for central vision and 25 for peripheral vision.

The difficulty of each subsequence screen was increased, decreasing the projecting times from 400 to 40 ms and adding letters as follows: four letters until 16 slides, five letters from slide 17 to 21 and six letters in the last four slides. In peripheral vision, groups of 4 numbers were exhibited until slide 19, five numbers from 20 to 23, and six numbers in the last two slides. All the screens show up immediately after pressing the space bar on the laptop, and the athlete called out the perceived letters or numbers. The final score corresponds to the most difficult screen called out, with all the correct numbers for that slide.

Variables

Demographic measures were age (years), sex (male and female), shooter level (elite and non-elite, being elite those athletes who had been selected to compete representing Spain internationally), discipline (pistol and trap), training hours per week, years of practice/experience, visual correction in normal life (no/yes), visual correction in sports practice (no/yes), dominant eye (left/right), dominant hand (left/right) and crossed dominance (no/yes) and performance (score in competition).

On the other hand, the visual variables were the following: Binocular visual acuity (BVA) in decimal scale; Binocular Accommodation Facility (BAF) in cycles per minute; dominant eye (MAF), right or left; Stereopsis in cm as both the average of the three attempts and the maximum value obtained; and visual recognition time (VRT) divided in central vision (letters), peripheral vision (numbers), and total (letters plus numbers) measured all as the number of correct letters and/or numbers identified.

Statistical analysis

Demographic and descriptive variables were reported as mean and standard deviations ($M \pm SD$), adjusted mean and standard errors ($M_{adj} \pm SE$), frequencies, and percentages. To verify the normal distribution, the distribution of the studentized residuals was analyzed using the Shapiro-Wilk test ($p > 0.05$). Furthermore, outliers with studentized residuals greater than ± 3 standard deviations were analyzed. Leverage or influence points were assessed using leverage values and Cook's distance, respectively.

To examine whether the distribution of the shooters differed according to the level of competition and the discipline of the shoot, a chi-square homogeneity test was conducted. When the sample size did not meet the minimum expected frequency requirements, Fisher's exact test was applied. Furthermore, to evaluate differences in demographic and sport-related characteristics according to level and modality, an initial analysis was performed using independent sample t-tests, with Levene's test used to verify the assumption of homogeneity of variances.

Furthermore, two-way ANCOVAs were performed to examine the effects of sex, modality, and competition level on optometric measures, with age serving as a covariate. The linear relationship between age and optometric variables was assessed for each group by visual inspection of a scatterplot. The homogeneity of the regression slopes was determined by comparing the two-way ANCOVA model with and without interaction terms ($p > 0.05$). To test for homoskedasticity within groups, visual inspection of the studentized residuals plotted against the predicted values for each group was performed. Levene's test for homogeneity of variance ($p > 0.05$) was used to confirm homogeneity of variances. Furthermore, to analyze the simple main effects of sex, modality and competition level of the shooters, a Bonferroni adjustment of the level of statistical significance ($p < 0.025$) was performed.

The effect size was calculated using Cohen's d and interpreted using three cutoff points: small ($d = 0.2$), medium ($d = 0.5$) and large ($d = 0.8$) and eta partial η^2 , being $\eta^2 = 0.01$ a small effect, $\eta^2 = 0.06$ a medium effect and $\eta^2 = 0.14$ a large effect (Cohen, 1988). Statistical analyzes were performed using IBM SPSS Statistics (version 29.0; IBM Corp.) and the level of significance was established at $p < 0.05$.

Results

The homogeneity chi-square test confirmed significant differences between the two modalities in the proportion of participants according to sex ($p < 0.001$), visual correction in sport ($p < 0.001$), and visual correction in daily life ($p = 0.004$). Furthermore, elite shooters showed a lower proportion of visual correction in their daily lives compared to non-professional shooters ($p = 0.048$). No significant differences were observed in the remaining comparisons ($p > 0.05$; Table 1).

Table 1. Sample frequency distribution of shooter characteristics according to their level and modality

Variables	Full sample (n = 122)		Elite (n = 33)		Non-elite (n = 89)		P	Pistol (n = 53)		Trap (n = 69)		P
	n	%	n	%	n	%		n	%	n	%	
Sex												
Women	28	23.0	5	15.2	23	25.8	0.212	23	43.4	5	7.2	< 0.001***
Men	94	77.0	28	84.8	66	74.2		30	56.6	64	92.8	
VC (daily)												
No	75	61.5	25	75.8	50	56.2	0.048*	25	47.2	50	72.5	0.004**
Yes	47	38.5	8	24.2	39	43.8		28	52.8	19	27.5	
VC (sport)												
No	77	63.1	25	75.8	52	58.4	0.078	24	45.3	53	76.8	< 0.001***
Yes	45	36.9	8	24.2	37	41.6		29	54.7	16	23.2	
Dominant eye												
Left	19	15.6	6	18.2	13	14.6	0.629	9	17.0	10	14.5	0.660
Right	103	84.4	27	81.8	76	85.4		44	83.0	59	85.5	
Dominant hand												
Left	10	8.2	3	9.1	7	7.9	0.826	2	3.8	8	11.6	0.060
Right	112	91.8	30	90.9	82	92.1		51	96.2	61	88.4	
Cross dominance												
No	113	91.0	30	90.9	81	91.0	0.986	46	86.8	65	94.2	0.070
Yes	11	9.0	3	9.1	8	9.0		7	13.2	4	5.8	

Abbreviations: n = number of participants; p = level of significance; VC = visual correction; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

On the other hand, the t-test demographic analysis by modality showed that male pistol shooters were older than the trap shooters ($M = 7.07$, 95% CI [13.82, 0.32], $t_{(92)} = 2.08$, $p = 0.023$, $d = 0.46$). No significant differences were found in the remaining variables analyzed ($p < 0.05$). Furthermore, the comparison between elite and non-elite showed higher ages values for the non-elite group in men ($M = 9.03$, 95% CI [15.81, 2.24],

$t_{(92)} = 2.64$, $p = 0.010$, $d = 0.60$) and for the entire sample ($M = 6.66$, 95% CI [12.23, 1.09], $t_{(120)} = 2.38$, $p = 0.020$, $d = 0.44$) and lower experience values in the non-elite female group than in the elite group ($M = -9.84$, 95% CI [-16.01, -3.68], $t_{(92)} = -3.28$, $p = 0.003$, $d = -1.62$). Additionally, the non-elite group showed less performance than the elite group in the female pistol event ($M = -19.98$, 95% CI [-31.01, -8.96], $t_{(21)} = -3.78$, $p = 0.001$, $d = -0.96$) and in the male trap event ($M = -4.30$, 95% CI [-8.13, -0.48], $t_{(62)} = -2.25$, $p = 0.028$, $d = -0.59$). No significant differences were found in the rest of the variables analyzed ($p < 0.05$) (See Table 2). Lastly, with regard to the comparison by sex, men were older than women ($M = 8.37$, 95% CI [1.92, 14.83], $t_{(120)} = 2.57$, $p = 0.011$, $d = 0.55$), but no more significant differences were found in the rest of the variables analyzed ($p < 0.05$).

Table 2. Sports demographic and performance characteristics of the shooters by modality and competition level.

Baseline characteristic	Full sample Pistol (n = 122)		Trap (n = 69)		P (Cohen's d)		Elite (n = 33)		Non-Elite (n = 89)		P (Cohen's d)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Age (years)												
Both sexes	36.13	15.48	37.76	17.17	34.88	14.05	0.312(0.19)	31.27	12.73	37.93	16.08	0.020*(0.44)
Female	29.68	13.29	31.09	14.01	23.20	7.05	0.091(0.60)	28.80	8.93	29.87	14.22	0.874(0.08)
Male	38.05	15.63	42.87	17.82	35.80	14.08	0.040*(0.46)	31.71	13.37	40.74	15.83	0.010*(0.60)
Experience (years)												
Both sexes	11.59	9.92	10.53	8.37	12.41	10.96	0.286(0.19)	13.55	10.60	10.87	9.62	0.187(0.27)
Female	8.11	7.10	8.40	6.78	6.80	9.18	0.656(-0.22)	16.20	7.85	6.36	5.70	0.003**(1.62)
Male	12.63	10.43	12.17	9.18	12.84	11.03	0.771(0.07)	13.07	11.07	12.44	10.23	0.790(0.06)
Workload (hours/week)												
Both sexes	6.16	7.31	5.21	2.94	6.89	9.35	0.164(0.23)	8.70	12.12	5.21	4.10	0.115(-0.49)
Female	4.82	3.06	4.83	3.35	4.80	1.10	0.987(-0.01)	4.80	2.17	4.83	3.26	0.987(-0.51)
Male	6.55	8.14	5.50	2.60	7.05	9.69	0.393(0.19)	9.39	13.05	5.35	4.37	0.120(0.01)
Pistol score (points)												
Female								547.3	3.5	527.3	21.9	0.001**(0.96)
Male								549.6	17.3	536.1	19.4	0.159(0.71)
Trap score (points)												
Female								1080.0	2.8	99.3	3.1	0.050(2.91)
Male								113.3	7.8	109.0	7.1	0.028*(0.59)

Abbreviations: n = number of participants; p = level of significance. * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

After preliminary check of the distribution frequencies and demographic variables, an initial independent t-test analysis of visual skill was performed (Table 3). Comparison by modalities reveals that trap shooters obtained higher results in BVA ($M = 0.19$, 95% CI [0.09, 0.31], $t_{(120)} = 3.60$, $p < 0.001$, $d = 0.63$). On the contrary, trap shooters showed lower values than pistol shooters in maximum stereopsis ($M = -3.39$, 95% CI [-6.50, -0.28], $t_{(120)} = -2.16$, $p = 0.033$, $d = -0.39$), VRT for central vision ($M = -6.82$, 95% CI [-13.57, -0.08], $t_{(120)} = -2.00$, $p = 0.048$, $d = -0.37$), VRT for peripheral vision ($M = -6.13$, 95% CI [-11.65, -0.61], $t_{(120)} = -2.20$, $p = 0.030$, $d = -0.40$) and in the total values of VRT ($M = -6.48$, 95% CI [-12.24, -0.72], $t_{(120)} = -2.23$, $p = 0.028$, $d = -0.41$). No significant differences were observed in the remaining variables according to the type of firearm used ($p > 0.05$). On the other hand, the analysis by the of the shooters of competition level showed that the elite shooters obtained better scores in BVA ($M = 0.21$, 95% CI [0.08, 0.32], $t_{(120)} = 3.26$, $p = 0.001$, $d = 0.66$), BAF ($M = 3.64$, 95% CI [1.40, 5.87], $t_{(120)} = 3.22$, $p = 0.002$, $d = 0.66$), VRT for central vision ($M = 9.94$, 95% CI [2.50, 17.38], $t_{(120)} = 2.64$, $p = 0.009$, $d = 0.54$), VRT for total value ($M = 6.84$, 95% CI [0.40, 13.28], $t_{(120)} = 2.10$, $p = 0.038$, $d = 0.43$) and nearly significant differences in MAF ($M = 2.39$, 95% CI [0.02, 4.80], $t_{(120)} = 1.96$, $p = 0.052$, $d = 0.40$). For the rest of the variables, no significant differences were found ($p > 0.05$).

Table 3. Optometric measures shooters comparisons according to their modality and competition level.

Visual Skills	Modality		Competition level			
	Trap (n = 69)	Pistol (n = 53)	Effect size Cohen's D	Elite (n = 33)	Non-elite (n = 89)	Effect size Cohen's D
BVA	1.30 ± 0.34	1.10 ± 0.25***	0.63	1.36 ± 0.36	1.16 ± 0.29**	0.66
BAF	5.19 ± 5.85	4.72 ± 5.66	0.08	7.64 ± 6.55	4.00 ± 5.12**	0.66

MAF	4.65 ± 6.24	4.30 ± 5.84	0.06	6.24 ± 6.88	3.85 ± 5.61	0.40
Mean Stereopsis	8.18 ± 4.90	10.08 ± 6.18	-0.35	8.36 ± 4.88	9.24 ± 5.78	0.16
Max Stereopsis	12.86 ± 7.75	16.25 ± 9.61*	-0.39	13.18 ± 7.17	14.75 ± 9.25	-0.18
VRT Central	70.42 ± 20.54	77.25 ± 15.88*	-0.37	80.64 ± 16.40	70.70 ± 19.13**	0.54
VRT Peripheral	58.30 ± 16.46	64.43 ± 13.57*	-0.40	63.70 ± 18.16	59.96 ± 14.39	0.24
VRT – Total	64.36 ± 17.52	70.84 ± 13.58*	-0.41	72.17 ± 16.57	65.33 ± 15.74*	0.43

Notes: Cohen's d values are reported in the right column. Data are represented as mean ± SD. Abbreviations: BAF: binocular accommodation facility; BVA: binocular visual acuity; MAF: monocular accommodative facility; VRT: visual recognition time; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

Furthermore, to avoid results biases according to the sample distribution and the initial results of visual skills, an in-depth analysis (three 2-way ANCOVA) was performed that controlled the age for independent variables of sex, modality, and level of competition (see Table 4). A two-way ANCOVA was conducted to investigate the impact of sex and modality on optometric measures. The interaction between sex and modality was not statistically significant for any optometric variables ($p > 0.05$).

Regarding the main effects, the influence of the modality was found to be statistically significant in the male group, with higher values in mean absolute stereopsis ($F_{(1, 117)} = 4.019$, $p = 0.047$, partial $\eta^2 = 0.033$), VRT for central vision ($F_{(1, 117)} = 7.847$, $p = 0.006$, partial $\eta^2 = 0.063$), VRT for peripheral vision ($F_{(1, 117)} = 5.870$, $p = 0.017$, partial $\eta^2 = 0.048$) and total VRT value ($F_{(1, 117)} = 7.985$, $p = 0.006$, partial $\eta^2 = 0.064$) for pistol than for trap shooters. On the effect of modality on women and the effect of sex in pistol and trap shooters were not statistically significant for any optometric measures ($p > 0.05$).

A two-way ANCOVA was performed to examine the effects of shooter sex and competition level on optometric measures (Table 4). There was a statistically significant interaction between sex and the level of competition in BVA ($F_{(1, 117)} = 5.962$, $p = 0.016$, partial $\eta^2 = 0.048$). Regarding the main effects, men had higher BVA values than women in the non-elite group ($F_{(1, 117)} = 11.256$, $p = 0.001$, partial $\eta^2 = 0.088$). On the other hand, the main effect of the level of competition in the female's group was statistically significant ($F_{(1, 117)} = 10.132$, $p = 0.002$, partial $\eta^2 = 0.080$) with higher BVA values in the elite group than in the non-elite group. Furthermore, the level of impact of the competition in the male's group was statistically significant ($F_{(1, 117)} = 6.474$, $p = 0.012$, partial $\eta^2 = 0.052$) with higher adjusted mean BAF values in the elite group than in the non-elite group. For the rest of the interactions and comparisons analyzed in the optometric variables, no significant differences were found ($p < 0.05$).

Lastly, a two-way ANCOVA was performed to investigate the effects of the shooting modality and the level of competition on the optometric measures (Table 4). The interaction between shooter modality and competition level was not statistically significant for BVA, BAF, VRT central, and VRT total ($p > 0.05$). However, the main effect of the modality in the non-elite group was statistically significant ($F_{(1, 117)} = 6.896$, $p = 0.010$, partial $\eta^2 = 0.056$) with higher adjusted mean BVA values for non-elite trap shooters than non-elite pistol shooters. Furthermore, the main effect of the competition level on the trap shooter group was statistically significant ($F_{(1, 117)} = 7.946$, $p = 0.006$, partial $\eta^2 = 0.064$) with higher adjusted mean BAF values for elite trap shooters than for non-elite shooters. Regarding VRT, the main effect of the level of competition on trap shooters group was statistically significant ($F_{(1, 117)} = 5.550$, $p = 0.020$, partial $\eta^2 = .445$), which is the adjusted mean VRT for central vision higher in elite trap shooters than in nonelite shooters. In addition, the effect of the modality of competition in the non-elite group was statistically significant ($F_{(1, 117)} = 7.905$, $p = 0.006$, partial $\eta^2 = 0.063$). The adjusted mean VRT for central vision was higher for non-elite pistol shooters than for non-elite trap shooters.

The peripheral vision analysis showed a statistically significant interaction between shooter modality and competition level ($F_{(1, 117)} = 4.153$, $p = 0.044$, partial $\eta^2 = 0.034$). The impact of modality in the non-elite group was statistically significant ($F_{(1, 117)} = 12.405$, $p < 0.001$, partial $\eta^2 = 0.096$). The adjusted mean VRT for peripheral vision in the non-elite group was higher in pistol than in trap. Furthermore, the effect of competition level on the trap shooter group was statistically significant ($F_{(1, 117)} = 4.604$, $p = 0.034$, partial $\eta^2 = 0.038$). The adjusted mean VRT for peripheral vision was higher for elite than for non-elite trap shooters.

Lastly, the total VRT analysis did not show a statistically significant interaction between the shooting mode and competition level ($F_{(1, 117)} = 1.092$, $p = .298$, partial $\eta^2 = 0.009$). However, the effect of competition level on the trap shooter group was statistically significant ($F_{(1, 117)} = 5.868$, $p = 0.017$, partial $\eta^2 = 0.048$). The adjusted mean Total VRT was higher for elite trap shooters than for non-elite shooters. Furthermore, the effect of competition mode in the non-elite group was statistically significant ($F_{(1, 117)} = 11.286$, $p = 0.001$, partial $\eta^2 = 0.088$). The adjusted mean Total VRT was higher for non-elite pistol shooters than for non-elite trap shooters. For the rest of the interactions and comparisons by shooter modality and competition level analyzed in the optometric variables, no significant differences were found ($p < 0.05$).

Table 4. Means, Standard Deviations, Adjusted Means, and Standard Errors for optometric measures for shooters according to their sex and modality of competition, sex and level of competition and modality and level of competition.

Visual Skills		Female (n = 28)		Male (n = 94)		Nonelite (n = 89)		Elite (n = 33)		Non-elite (n = 89)		Elite (n = 33)	
		Pistol	Trap	Pistol	Trap	Female	Male	Female	Male	Pistol	Trap	Pistol	Trap
BVA	M(SD)	1.07(0.24)	1.40(0.42)	1.13(0.27)	1.29(0.34)	1.05(0.22)	1.20(0.30)	1.50(0.35)	1.33(0.36)	1.08(0.22)	1.24(0.33)	1.25(0.38)	1.40(0.35)
	M _{adj} (SE)	1.03(0.06)	1.30(0.13)	1.18(0.05)	1.29(0.04)	1.00(0.06)	1.24(0.04) ^{ab}	1.44(0.13) ^{ab}	1.30(0.05)	1.09(0.04)	1.25(0.04) ^{ab}	1.24(0.10)	1.36(0.06)
BAF	M(SD)	6.00(6.09)	6.40(5.86)	3.73(5.19)	5.09(5.89)	5.91(6.13)	3.33(4.59)	6.80(5.59)	7.79(6.78)	4.53(5.53)	3.45(4.67)	5.75(6.63)	8.24(6.54)
	M _{adj} (SE)	5.02(1.06)	3.89(2.28)	5.04(0.94)	5.03(0.63)	4.83(1.03)	4.13(0.62)	5.53(2.19)	7.02(0.93) ^{ab}	4.92(0.73)	3.71(0.73)	5.51(1.72)	7.19(0.99) ^{ab}
MAF	M(SD)	5.91(6.62)	7.20(7.33)	3.07(4.92)	4.45(6.16)	6.26(6.76)	3.02(4.93)	5.60(6.69)	6.36(7.03)	4.22(6.05)	3.47(5.16)	4.75(4.77)	6.72(7.45)
	M _{adj} (SE)	4.98(1.13)	4.80(2.44)	4.32(1.01)	4.39(0.67)	5.17(1.13)	3.82(0.67)	4.32(2.39)	5.59(1.02)	4.62(0.80)	3.74(0.80)	4.50(1.88)	5.63(1.08)
Mean Abs Stereopsis	M(SD)	9.13(4.25)	6.60(2.31)	10.80(7.32)	8.31(5.03)	8.39(4.24)	9.54(6.23)	10.00(3.09)	8.07(5.12)	9.91(6.08)	8.56(5.45)	11.00(7.05)	7.52(3.76)
	M _{adj} (SE)	9.13(1.16)	6.59(2.51)	10.80(1.03)	8.31(0.69) ^{ab}	8.43(1.19)	9.51(0.71)	10.05(2.52)	8.10(1.07)	9.89(0.83)	8.55(0.84)	11.01(1.96)	7.57(1.13)
Maximum Stereopsis	M(SD)	15.61(9.29)	9.80(1.64)	16.73(9.97)	13.09(7.99)	14.26(8.71)	14.92(9.48)	16.00(9.59)	12.68(6.75)	16.11(9.72)	13.36(8.62)	17.00(9.50)	11.96(5.98)
	M _{adj} (SE)	15.73(1.83)	10.10(3.94)	16.58(1.62)	13.10(1.08)	14.49(1.87)	14.76(1.11)	16.26(3.96)	12.84(1.68)	16.05(1.30)	13.32(1.31)	17.04(3.07)	12.14(1.76)
VRT-Central Vision	M(SD)	76.70(18.46)	77.40(7.80)	77.67(13.89)	69.88(21.15)	74.96(17.50)	69.21(19.58)	85.40(11.80)	79.79(17.12)	75.60(16.04)	65.68(20.86)	86.50(11.82)	78.76(17.39)
	M _{adj} (SE)	74.36(3.69)	71.41(7.96)	80.79(3.28)	69.72(2.19) ^{ab}	72.75(3.77)	70.84(2.25)	82.82(7.98)	78.23(3.39)	76.43(2.56)	66.23(2.58) ^{ab}	85.97(6.05)	76.48(3.47) ^{ab}
VRT-Peripheral Vision	M(SD)	65.70(14.66)	64.20(10.35)	63.47(12.84)	57.84(16.81)	63.57(14.05)	58.70(14.40)	74.00(9.75)	61.86(18.80)	65.11(12.54)	54.68(14.38)	60.63(18.97)	64.68(18.18)
	M _{adj} (SE)	64.02(3.07)	59.92(6.62)	65.70(2.73)	57.73(1.82) ^{ab}	61.82(3.15)	59.98(1.88)	71.96(6.67)	60.63(2.83)	65.76(2.13)	55.11(2.15) ^{ab}	60.21(5.04)	62.89(2.90) ^{ab}
VRT - Total	M(SD)	71.20(15.67)	70.80(5.07)	70.57(12.01)	63.86(18.05)	69.26(14.70)	63.95(15.97)	79.70(8.71)	70.82(17.37)	70.36(13.43)	60.18(16.40)	73.56(15.07)	71.72(17.29)
	M _{adj} (SE)	69.19(3.15)	65.66(6.78)	73.24(2.80)	63.73(1.87) ^{ab}	67.23(3.23)	65.41(1.93)	77.39(6.85)	69.43(2.91)	71.09(2.19)	60.67(2.21) ^{ab}	73.09(5.17)	69.68(2.97) ^{ab}

Notes: A = differences between modalities in groups with the same sex, B = differences between levels of competition in groups with the same sex; C = differences between sex in groups with the same competition level; D= differences between modalities in groups with the same competition level. E= differences between the level of competition in groups with the same modality. Level of significance = * p < 0.05; ** p < 0.01; *** p < 0.001. Data are represented as mean ± SD and adjusted mean ± SE. BVA: binocular visual acuity; BAF: binocular accommodation facility; MAF: monocular accommodative facility; VRT: visual recognition time.

Discussion

This study aimed to examine some visual skills of shooters according to modality, level of competition, and sex. The main findings of the study revealed that elite shooters had better levels of BVA, BAF, central VRT, and VRT total. According to the modality, the trap group had better BVA and stereopsis than the pistol shooters, while the pistol group had better VRT than the trap shooters. Also, in non-elite group males had better BVA than females.

Although pistol shooting is considered a precision sport, the present study found that trap shooters have better visual acuity than pistol shooters. However, it may be a contributing factor, since male pistol shooters were significantly older than trap shooters. Furthermore, as shown in Table 1, pistol shooters reported a higher rate of visual correction use compared to trap shooters. Considering that visual acuity gradually declines after approximately 29 years of age (Elliot et al., 1995), these findings could be consistent with age-related visual changes. Additionally, while trap shooters typically shoot binocularly, pistol shooters mainly rely on monocular vision, closing one eye to avoid diplopia. Over time, this practice may promote monocular adaptation (Garaszczuk et al., 2025b), which could explain the lower BVA observed in pistol shooters due to suppression of the non-dominant eye.

Interestingly, despite being older, males in the non-elite group exhibited better BVA than females. Other studies have(Garaszczuk et al., 2025a)reported that national-level shooters demonstrated superior visual acuity despite their older age. Given that BVA can improve with training (Deveau et al., 2014), it is reasonable to assume that the superior BVA observed in non-elite males may stem from their longer training experience, nearly twice as many years as females (see Table 2). Furthermore, as expected, our results were consistent with previous research, since the elite group also exhibited better visual acuity than the non-elite group.(Garaszczuk et al., 2025a; Mon-López et al., 2022b)

Regarding stereopsis, our results showed that pistol shooters exhibited higher maximum stereopsis thresholds than trap shooters. In line with previous literature, stereopsis has been identified as crucial for estimating the speed and position of objects in space (Buscemi et al., 2024) and appears to play a more decisive role in some sports disciplines than in others (Presta et al., 2021). Considering that in trap shooting the target can reach speeds of up to 100 km·h⁻¹ (Causer et al., 2010) and emerges from unpredictable locations and directions (Nascimento, Alvarez-Peregrina, et al., 2021), this visual skill is likely to be particularly critical for trap shooters. However, since stereopsis can be improved by training (J. F. Clark et al., 2015), it seems reasonable to assume that trap shooters can develop more refined stereoscopic abilities, as their performance depends on accurately perceiving and tracking fast-moving targets at greater distances.

However, the main differences were observed in the maximum stereopsis values, with no significant differences between skill levels. One possible explanation for this finding is that stereopsis is a visual function commonly engaged in daily activities such as walking, driving, or writing (O'connor & Tidbury, 2018).

Furthermore, higher maximum stereopsis values may reflect higher point errors in depth perception, which could be more critical in clay target shooting than in pistol shooting due to differences in the scoring system (hit / miss vs. graded numerical scores) (ISSF, 2025). Alternatively, the absence of other significant differences might be related to the limited number of participants within each subgroup in our study.

Trap and male elite shooters showed better BAF than non-elite shooters, whereas no significant differences were observed among pistol shooters. This superior accommodation performance probably reflects the visual demands of training (Mon-López et al., 2022a). Although Garaszczuk et al. reported no differences between shooters and controls, suggesting that accommodation is not affected by training and decreases with age (Garaszczuk et al., 2025a), other studies indicate that it can be improved through specific training protocols (Guo et al., 2024a; Jenerou et al., 2015). However, it is important to note that the nonelite group was older than the elite group (approximately 6 years older in the overall sample and 9 years among males), which may partly explain their lower accommodative performance due to age-related decline.

However, although the nature of the shooting disciplines might require different visual skills (Nascimento, Martinez-Perez, et al., 2021), requiring rapid adjustments for trap (Guo et al., 2024b), while pistol shooting must avoid looking at the stationary target 10 meters away and focus on the front sight (Mon-López et al., 2022a), no differences were found in BAF or MAF based on discipline. Surprisingly, this finding may suggest that both disciplines require similar levels of these visual skills, even though aiming in trap shooting is performed binocularly and the accommodative ability of the non-dominant eye is relatively unimportant, while pistol shooting is generally performed monocularly. However, these results should be interpreted with caution due to potential uncontrolled variables, the nonspecific nature of the test, and the limited sample size.

As expected, elite trap shooters demonstrated better VRT compared to the non-elite group. Consistent with previous research, elite shooters process and evaluate visual information faster (Burris et al., 2018; Reichow et al., 2011). In trap shooting, a broader perceptual span probably facilitates faster and more accurate target tracking, reducing the response time (Guo et al., 2024a). Therefore, this better VRT may allow elite shooters to detect and engage targets more efficiently, contributing to higher shooting performance.

On the contrary, pistol shooters outperformed trap shooters in total, central, and peripheral VRT. This advantage in central VRT may reflect the sustained focus required for front sight–target alignment in pistol shooting (Mon-López et al., 2022a); however, given the unpredictable target direction (ISSF, 2025) and limited shooting time (Abernethy & Neal, 1999) in trap, a better peripheral VRT would have been expected. However, the reason for this result remains unclear and warrants further investigation.

Limitations and future directions

Although this study is novel in evaluating visual skills in shooting modalities considering sex and skill level, several limitations should be acknowledged. The unequal distribution of female and elite participants may reflect the actual shooting population but could have reduced statistical power and masked other potential differences by sex and competition level. Future research should therefore aim for more balanced sample sizes. Furthermore, factors such as age distribution, visual correction rates, and criteria that define elite status can limit the generalizability of the findings, especially since other modalities such as rifle or skeet were not included. The absence of related visual measures, such as eye–hand coordination or quiet eye, also represents a limitation. Despite these limitations, this study provides valuable information on visual skill differences between pistol and trap shooters, offering practical guidance for coaches and optometrists in designing training programs and monitoring visual performance throughout the season.

Conclusion

This study represents a comprehensive empirical effort to map the visual architecture of target shooting disciplines and proves that shooting disciplines operate under distinct visual skill profiles governed by specific task constraints. Trap shooters, who must quickly locate, estimate depth, and intercept clay targets moving at high speeds, demonstrate superior binocular visual acuity (BVA) and stereoscopic thresholds. Conversely, pistol shooters, who are constrained by fine motor control, static target alignment, and rapid sight-picture processing, exhibit significantly faster central, peripheral, and total visual recognition times (VRT). Crucially, the finding that elite athletes consistently outperform non-elite counterparts in BVA, binocular accommodative facility (BAF), and visual recognition speed confirms that specialized oculomotor and perceptual-cognitive capabilities are distinct hallmarks of athletic expertise.

This manuscript establishes that specific visual skills are differentially recruited, trained, and altered depending on firing posture (monocular suppression in pistol vs. binocular alignment in trap), competition modality, and experience. Furthermore, the findings prove that elite-level advantages in accommodative facility and processing speed transcend normal age-related visual decline, establishing perceptual efficiency as a direct outcome of domain-specific practice.

Trap athletes require dynamic depth perception and wide-field target-tracking drills, whereas pistol shooters benefit from accommodative flipper routines to enhance sight-picture focus transitions and tachistoscopic speed training to minimize central processing latency.

These empirical insights should be translated into the work of national sports federations and high-performance training centers, in which standard clinical eye exams are insufficient. Optometrists and athletic coaches must adopt comprehensive sports vision diagnostic batteries that routinely evaluate binocular accommodative facility, dynamic stereopsis, and tachistoscopic perceptual speed alongside standard visual acuity. In addition, coaches and sports scientists should integrate customized visual training programs into periodized training plans. Future research should expand these results by combining optometric skill batteries with real-time gaze-tracking and kinematic aiming analyses.

Declaration of generative AI and AI-assisted technologies in the writing process,

The authors declare that during the preparation of this work the author(s) have not used IA or IA assisted technologies in the writing process.

Conflicts of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this document.

Declaration of funding No funding was received.

References

- Emery AF, Sekins KM. The use of heat transfer principles in designing optimal diathermy and cancer treatment modalities. *Int J Heat Mass Transf.* 1982;25(6). [https://doi.org/10.1016/0017-9310\(82\)90095-3](https://doi.org/10.1016/0017-9310(82)90095-3)
- Nascimento H, Martinez-Perez C, Alvarez-Peregrina C, Sánchez-Tena MÁ. Citations network analysis of vision and sport. *Int J Environ Res Public Health.* 2021;17(20):7574. <https://doi.org/10.3390/ijerph17207574>
- Laby DM, Appelbaum LG. Vision and on-field performance: a critical review of visual assessment and training studies with athletes. *Optometry and Vision Science.* 2021;98(7):723-731. <https://doi.org/10.1097/OPX.0000000000001729>
- Mon-López D, Bernardez-Vilaboa R, Sillero-Quintana M, Alvarez Fernandez-Balbuena A. Air shooting competition effects on visual skills depending on the sport level. *Eur J Sport Sci.* 2022;22(3):336-343. <https://doi.org/10.1080/17461391.2021.1874540>
- ISSF. General Technical Rules. 2025. Accessed April 20, 2023. https://www.issf-sports.org/theissf/rules_and_regulations/general_technical_rules.ashx
- Causar J, Bennett SJ, Holmes PS, Janelle CM, Williams AM. Quiet eye duration and gun motion in elite shotgun shooting. *Med Sci Sports Exerc.* 2010;42(8):1599-1608. <https://doi.org/10.1249/mss.0b013e3181d1b059>
- Erickson GB. *Sports Vision: Vision Care for the Enhancement of Sports Performance.*; 2020. <https://doi.org/10.1016/b978-0-323-75543-6.01001-9>
- Guo Y, Yuan T, Peng J, Deng L, Chen C. Impact of sports vision training on visuomotor skills and shooting performance in elite skeet shooters. *Front Hum Neurosci.* 2024;18:1476649. <https://doi.org/10.3389/fnhum.2024.1476649>
- Erickson GB. Optimizing visual performance for sport. *Adv Ophthalmol Optim.* 2018;3(1):1-19. <https://doi.org/10.1016/j.yaoo.2018.05.001>
- Güler G, Şimşek D, Tuncer S, Mon-López D. Evaluation of physiological parameters and gaze behaviour of air pistol shooters related to performance outcomes. *Int J Perform Anal Sport.* 2024;24(3):218-229. <https://doi.org/10.1080/24748668.2023.2280348>
- Shah E, Chow J, Exercise MLJ of S&, 2020 undefined. Anxiety on Quiet Eye and Performance of Youth Pistol Shooters. *Journal of Sport and Exercise Psychology.* 2020;42(4). <https://doi.org/10.1123/jsep.2019-0174>
- Di Russo F, Pitzalis S, Spinelli D. Fixation stability and saccadic latency in elite shooters. *Vision Res.* 2003;43(17):1837-1845. [https://doi.org/10.1016/s0042-6989\(03\)00299-2](https://doi.org/10.1016/s0042-6989(03)00299-2)
- Garaszczuk IK, Jenczewska W, Asejczyk M. Superior monocular visual function but compromised binocular balance in precision shooters compared to age and refraction matched controls. *Sci Rep.* 2025;15(1). <https://doi.org/10.1038/s41598-025-14497-9>
- Zimmerman AB, Lust KL, Bullimore MA. Visual acuity and contrast sensitivity testing for sports vision. *Eye Contact Lens.* 2011;37(3):153-159. <https://doi.org/10.1097/icl.0b013e31820d12f4>
- Erickson GB. Visual performance assessments for sport. *Optometry and Vision Science.* 2021;98(7):672-680. <https://doi.org/10.1097/OPX.0000000000001731>
- Rienhoff R, Tirp J, Strauß B, Baker J, Schorer J. The 'Quiet Eye' and Motor Performance: A Systematic Review Based on Newell's Constraints-Led Model. *Sports Medicine.* 2016;46(4):589-603. <https://doi.org/10.1007/s40279-015-0442-4>
- Gao Y, Chen L, Yang S nan, et al. Contributions of visuo-oculomotor abilities to interceptive skills in sports. *Optometry and Vision Science.* 2015;92(6):679-689. <https://doi.org/10.1097/OPX.0000000000000599>
- Uchida Y, Kudoh D, Higuchi T, Honda M, Kanosue K. Dynamic visual acuity in baseball players is due to superior tracking abilities. *Med Sci Sports Exerc.* 2013;45(2):319-325. <https://doi.org/10.1249/mss.0b013e31826fec97>
- Laby DM, Davidson JL, Rosenbaum LJ, et al. The visual function of professional baseball players. *Am J Ophthalmol.* 1996;122(4):476-485. <https://doi.org/10.1038/s41598-019-52546-2>

- Rodrigues P. Sports vision: influence on athlete's performance. *Acta Sci Ophthalmol*. 2020;3:61-68. <https://doi.org/10.31080/asop.2020.03.0118>
- O'Connor AR, Tidbury LP. Stereopsis: are we assessing it in enough depth? *Clin Exp Optom*. 2018;101(4):485-494. <https://doi.org/10.1111/cxo.12655>
- Presta V, Vitale C, Ambrosini L, Gobbi G. Stereopsis in sports: Visual skills and visuomotor integration models in professional and non-professional athletes. *Int J Environ Res Public Health*. 2021;18(21):11281. <https://doi.org/10.3390/ijerph182111281>
- Boden LM, Rosengren KJ, Martin DF, Boden SD. A comparison of static near stereo acuity in youth baseball/softball players and non-ball players. *Optometry-Journal of the American Optometric Association*. 2009;80(3):121-125. <https://doi.org/10.1016/j.optm.2008.06.009>
- Reinkemeier H, Bühlmann G. *Pistol Shooting-the Olympic Disciplines: Technique, Training, Tactics, Psychology, Guns*. Verlag MEC; 2013.
- Garaszczuk IK, Jenczewska W, Asejczyk M. Superior monocular visual function but compromised binocular balance in precision shooters compared to age and refraction matched controls. *Sci Rep*. 2025;15(1):28816. <https://doi.org/10.1038/s41598-025-14497-9>
- Clark J, Betz B, Borders L, Kuehn-Himmler A, Hasselfeld K, Divine J. Vision training and reaction training for improving performance and reducing injury risk in athletes: Sports vision training. *Journal of Sports and Performance Vision*. 2020;2(1):e8-e16. <https://doi.org/10.22374/jspv.v2i1.4>
- Reichow AW, Garchow KE, Baird RY. Do scores on a tachistoscope test correlate with baseball batting averages? *Eye Contact Lens*. 2011;37(3):123-126. <https://doi.org/10.1097/icl.0b013e3182188a77>
- Burris K, Vittetoe K, Ramger B, et al. Sensorimotor abilities predict on-field performance in professional baseball. *Sci Rep*. 2018;8(1):116. <https://doi.org/10.1038/s41598-017-18565-7>
- Mann DTY, Williams AM, Ward P, Janelle CM. Perceptual-cognitive expertise in sport: A meta-analysis. *J Sport Exerc Psychol*. 2007;29(4):457-478. <https://doi.org/10.1123/jsep.29.4.457>
- Mon-López D, Bernardez-Vilaboa R, Sillero-Quintana M, Alvarez Fernandez-Balbuena A. Air shooting competition effects on visual skills depending on the sport level. *Eur J Sport Sci*. 2022;22(3). <https://doi.org/10.1080/17461391.2021.1874540>
- Lord SR, Dayhew J. Visual risk factors for falls in older people. *J Am Geriatr Soc*. 2001;49(5):508-515. <https://doi.org/10.1046/j.1532-5415.2001.49107.x>
- Clark JF, Ellis JK, Bench J, Khoury J, Graman P. High-performance vision training improves batting statistics for University of Cincinnati baseball players. *PLoS One*. 2012;7(1):e29109. <https://doi.org/10.1371/journal.pone.0029109>
- Cohen J. Statistical power analysis for the behavioural sciences. [Internet]. Routledge; 2013. <https://doi.org/10.4324/9780203771587>
- Elliot DB, Yang KCH, Whitaker D. Visual acuity changes throughout adulthood in normal, healthy eyes: seeing beyond 6/6. *Optometry and vision science*. 1995;72(3):186-191. <https://doi.org/10.1097/00006324-199503000-00006>
- Deveau J, Ozer DJ, Seitz AR. Improved vision and on-field performance in baseball through perceptual learning. *Current Biology*. 2014;24(4):R146-R147. <https://doi.org/10.1016/j.cub.2014.01.004>
- Buscemi A, Mondelli F, Biagini I, Gueli S, D'Agostino A, Coco M. Role of sport vision in performance: systematic review. *J Funct Morphol Kinesiol*. 2024;9(2):92. <https://doi.org/10.3390/jfkm9020092>
- 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;18(15):8147. <https://doi.org/10.3390/ijerph18158147>
- Clark JF, Colosimo A, Ellis JK, et al. Vision training methods for sports concussion mitigation and management. *J Vis Exp*. 2015;(99):52648. <https://doi.org/10.3791/52648-v>
- Jenerou A, Morgan B, Buckingham RS. A Vision Training Program's Impact on Ice Hockey Performance. *Optom Vis Perform*. 2015;3(2). Accesible in <https://www.ovjournal.org/uploads/2/3/8/9/23898265/3-2-5.pdf>
- Guo Y, Yuan T, Peng J, Deng L, Chen C. Impact of sports vision training on visuomotor skills and shooting performance in elite skeet shooters. *Front Hum Neurosci*. 2024;18. <https://doi.org/10.3389/fnhum.2024.1476649>
- Abernethy B, Neal RJ. Visual characteristics of clay target shooters. *J Sci Med Sport*. 1999;2(1):1-19. [https://doi.org/10.1016/s1440-2440\(99\)80180-7](https://doi.org/10.1016/s1440-2440(99)80180-7)