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*Review*

# Nutrients With Optical and Antioxidant Properties to Enhance Sports Performance

Parimala Sivaperuman[1,2], Fraser C. Horn[1,3,†], James Stringham[1], Richard Swinburne[1], John Nolan[1,*,†]

[1]Nutrition Research Centre Ireland, School of Health Science, South East Technological University, X91 K236 Waterford, Ireland
[2]High Performance Sport Institute, Sport Excellence Singapore, 397630 Singapore, Singapore
[3]College of Optometry at Pacific University, Forest Grove, OR 97116, USA
*Correspondence: john.nolan@setu.ie (John Nolan)
[†]These authors contributed equally.

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**Abstract**

The science of nutrition related to sports performance has progressed extensively, particularly in terms of supporting precision sports such as shooting, archery, and electronic sports and games. There is a growing awareness of the critical role that visual function plays in sports performance. This awareness is particularly relevant given the existing empirical evidence that exposure to short-wavelength visible blue light can lead to photo-oxidative stress at the retina. Precision sports athletes frequently encounter this type of light during both training and competition, and factors such as duration and intensity of light exposure impact on performance. In the general population, research on the diet-derived macular carotenoids, including lutein (L), zeaxanthin (Z), and meso-zeaxanthin (MZ), has demonstrated their ability to combat photo-oxidative stress at the retina. These carotenoids not only act as powerful antioxidants, but also serve as a filter of short-wavelength blue light, thereby enhancing visual functions. Despite this science, there is a lack of robust evidence-based nutritional studies specifically targeting visual performance in athletes. This narrative review examines the biologically plausible scientific rationale supporting the hypothesis that macular carotenoids may enhance sport performance in athletes. To do this, we assessed studies reporting the visual characteristics in vision-dependent performance precision sports, and how performance is linked to specific nutrients of the eye.

**Keywords:** nutrition; antioxidants; sports performance; vision; eye

## 1. Introduction

The human eye is a vital sensory organ that processes approximately 80% of the information we gather from our external environment. As part of the central nervous system, the eye receives visual information and interprets it at the brain through electrical signals. When we look at an object, light reflects from the object onto the back of the eye, specifically onto the light-sensitive tissue known as the retina. The retina is packed with photoreceptors and connected nerve cells that turn the image into nerve impulses. These impulses travel through the cable-like optic nerves to the brain. At the brain, there is a special area called the visual cortex, which sits at the back of both hemispheres. This area receives most of the signals from the optic nerve and processes them; the left side of the hemisphere processes information from the right visual field and *vice versa* [1,2]. The synergetic work between the retina and visual cortex allow us to perceive three-dimensional (3-D) information, to give colour differentiation, brightness perception, contrast discrimination, depth perception, and patterns of objects around us [3]. All of this information helps us coordinate our eye movements and overall body actions, making it easier to navigate the world [3,4,5].

Over the past century, there has been considerable emphasis on the relationships between athletic performance and physical attributes of the athletes; however, there has been less of a focus on the relationship between visual functions and athletic performance [6,7]. As for most athletes, visual abilities are critical because movement of the athlete is triggered, controlled, and refined by accurate and good quality visual information [8]. The critical visual skills necessary can significantly differ from one sport to another, or even among different positions within the same sport, depending on the visual demands of that sport. Understanding the visual demands in sports and how the eyes and body coordinate is crucial in sports performance.

In this review, we discuss the unique visual demands of different sports. This includes specific focus on shooting, archery, and esports, which are areas of interest in my role as a nutritional sport scientist and core to my research thesis. Moreover, having access to these athletes as a nutritional scientist provides a unique opportunity to study their nutrition and visual performance, and how they are linked. Each of these sports, as mentioned above, presents distinct challenges in how the athletes receive visual information. For example, in target shooting and archery, athletes require efficient processing of stationary visual information, which helps improve motor responses during these sports [7,9]. For instance, athletes from these sports often endure long training and competition sessions, and they need to spot distant targets accurately, maintain stable fixations [10,11,12,13] and execute precise shots. They typically remain in one position until they take their shot or release the arrow. These athletes encounter challenges in outdoor environments that can significantly affect visibility. On the other hand, electronic sport (Esport) or electronic game (Egame) athletes and players spend extended periods in front of electronic digital screens, quickly tracking multiple objects to outplay their opponents. Beyond the dynamic visual demands of searching for objects on the screen, constant exposure to these devices can create additional challenges. These athletes and players must recover quickly and adapt to maintain optimal visual performance when performing these sports [7].

The visual physiological traits of elite athletes, novices, and non-athletes have been compared in studies. The research shows that elite athletes have a superior visual system, enabling them to process crucial visual information more effectively. These visual and cognitive processing abilities aid in executing shots with a more efficient motor response compared to novices and non-athletes. For example, Hughes et al. (1993) [14] conducted a cross-sectional study, which distinguished visual and psychomotor variables between elite, intermediate and novice table tennis players. They found that elite athletes had superior visual abilities (dynamic visual acuity, wider visual field and superior peripheral targeting) and psychomotor responses than novices [14]. Correspondingly, many studies have shown similar findings among athlete groups when compared to non-athletes [10,11,15,16,17,18,19]. Furthermore, research has shown that elite athletes possess better visual acuity [20,21] and improved contrast sensitivity [22] at their level of play. Nevertheless, it is worth acknowledging that some studies reported conflicting outcomes to the above, suggesting that athletes are, in fact, able to use visual information more effectively but do not possess a superior visual system compared to novices. For example, a study assessed visual functions, including visual clarity, contrast sensitivity, depth perception, near-far quickness, and target capture, among elite and intermediate-level soccer players. They found no differences in visual function between the two groups [18]. Helsen and Pauwels [23] study and a review from Abernethy (1986) [24] highlighted that the speed and accuracy of tactical decision-making, identification and usage of relevant information correlate to the corresponding expertise of athletes and novices alike. In other words, the greater the expertise of the player, the greater the efficiency, increase in selectivity and processing speed performance. At an elite level, where cognitive and skill levels are comparable among competitors, having superior visual abilities would logically offer an advantage [23,24]. In support of this notion, a study on visual performance and soccer skills suggested that athletes with better visual systems will have better soccer skills, although all players were equally motivated and physically fit [25]. Additionally, another study found that recall performance declined after nine trials, even among strong chess players. This suggests considerable proactive interference, despite expectations for improved performance with the familiar recall task [26]. Another study examined how contrast and trajectory of displacement of the target influence the dynamic visual acuity of elite soccer, basketball and waterpolo players. The findings showed variations in the dynamic visual acuity performance between horizontal and diagonal displacements across three sports, highlighting the importance of this visual function for the dynamic nature of sports performance [27]. Consequently, an athlete with poor vision could have a disadvantage compared to one with good vision, despite similar skills and experiences.

Nutrition is increasingly recognised as a key component of achieving optimal sporting performances, especially at the elite level [28]. Most efforts are directed towards muscle adaptation and recovery, particularly during intense training loads when athletes face chronic muscular and mental fatigue, potentially leading to injury and illness [29]. It should be noted that visual sporting performance is no exception as a healthy eye provides good vision for athletes [30]. There is substantial evidence supporting the beneficial properties of xanthophyll carotenoids (often referred to as macular carotenoids), specifically lutein (L), zeaxanthin (Z), and meso-zeaxanthin (MZ). These compounds play a vital role in maintaining eye health and enhancing visual function, particularly in protecting the retina from damage caused by light exposure and reducing photo-oxidative stress. The macula, which constitutes about 4% of the retina, mediates 90% of our vision, including most aspects of high-performance one's colour vision: fine color discrimination, spatial acuity, and motion detection [31,32]. This will be discussed in more detail later. Therefore, enhancing the health of the macula is vital for protecting and improving overall vision. This principle applies to both adults facing eye diseases [32,33,34]; as well as young, healthy individuals [30,35,36,37,38,39,40] highlighting the importance of incorporating these carotenoids into our diets for long-lasting eye health and function.

The role of targeted nutrition on visual performance in sports and maintaining good eye health ensures optimal vision for athletes [30]. Hammond and colleagues [41,42] have described the potential contribution of dietary L and Z carotenoids on visual performance in baseball sport. However, to date, no experimental studies have specifically examined the effects of dietary and/or supplemented L, Z, and MZ within the athletic population, to the best of our knowledge. Consequently, there is a need to understand the roles of these carotenoids better for the athlete population, as well as their effects on visual functions and sports performance in Olympic-class precision sports. This narrative review paper aims to discuss (i) the types and functional properties of macular carotenoids, (ii) the visual demands in shooting, archery, and Esport or Egame precision sports, and (iii) explore the proposed mechanism through which macular carotenoids may support and enhance visual function in precision sports. This discussion is based on existing evidence from both human and animal studies.

## 2. Materials and Methods

This narrative review was conducted between September 2023 to July 2025. We gathered English peer-reviewed manuscripts by searching electronic databases such as PubMed, Science Direct, Google Scholar, and Web of Science, from inception up to July 2025. The keywords used in the search included "nutrition", "macular carotenoids", "lutein", "zeaxanthin", "meso-zeaxanthin" or "antioxidants" along with terms related to "eye" or "sports" or "sports performance" AND "vision". The review included randomised controlled trials, descriptive and epidemiological studies, systematic reviews, and meta-analyses that outlined the roles of macular carotenoids, as well as dietary and supplementation strategies aimed at enhancing visual function and sports performance outcomes in both healthy individuals and athletes. Studies involving children and population with diseases were excluded. Given the limited evidence surrounding antioxidant nutrients in sports vision, a comprehensive and systematic overview of the recent developments regarding the impact of macular carotenoids on sports vision, as defined by PRISMA [43] or similar frameworks, was not feasible. Therefore, we followed the methodological guidelines proposed by Ferrari (2015) [44]. We intentionally kept the search period open to gather as much relevant information as possible, as we see value in including earlier original works in this narrative review. One limitation of our approach is the potential for biased in selection of literatures; nonetheless, this methodology enabled us to identify several key areas where macular carotenoids enhance visual functions that are essential for precision sports, which is our primary focus. This review search strategy comprised two steps. Step one involved reviewing abstracts and conclusions against the predetermined criteria to narrow our selection. Step two entailed retrieving full articles and reassessing them against the same criteria. Additionally, we examined the references in these articles to find related studies and included some relevant to our review.

## 3. Macular Carotenoids: Yellow Spot in Human Retina

Carotenoids, a family of pigmented compounds, are synthesized by certain domains of life, i.e., eukaryotes (such as plants, algae, and some fungi) and microorganisms (such as bacteria and archaea), but not by animals [45,46,47]. Approximately 1117 carotenoids exist in nature [47]. These hydrocarbon compounds are classified into two categories: carotenes and xanthophylls. The oxygenated derivatives are known as xanthophylls (XC) [48,49], a yellow-pigmented carotenoids which are abundant in nature [50]. L, Z, β-cryptoxanthin, capsanthin, astaxanthin, and fucoxanthin fall under the extensive group of XC. We will focus on specific xanthophyll carotenoids: L, Z, and MZ, which are the three carotenoids found at the macula, and which are central to the present review.

Lutein, Z and MZ are structural isomers. Zeaxanthin and MZ have slightly longer systems of conjugated double bonds than L, with two β-ring end groups. In contrast, L has one β-ring and one ε-ring at the end groups. The structural differences among these three carotenoids are notable: L has three chiral positions, described as 3R, 3'R, 6'R L. Zeaxanthin, and MZ differ in the spatial orientation of the hydroxyl group at the C3' chiral position. Zeaxanthin has an R chiral position in this orientation (described as 3R, 3'R Z), while MZ has an S spatial orientation (described as 3R, 3'S Z) [51].

Humans cannot synthesize carotenoids "de novo" and must selectively consume fruits (e.g., kiwi, red grapes, peach), vegetables (e.g., spinach, kale, corn), and eggs to obtain L and Z from their diet [52]. MZ is synthesized from L in the retina [53,54]. However, work by our research group has shown that 12 percent of the population appeared to be unable to generate MZ from L [55]. Therefore, MZ for these individuals must be provided in supplement form [56]. While not abundant in nature, it can also be found in edible fishes, shrimp, and hen eggs [39,57,58,59]. The human diet comprises up to 50 carotenoids [60]; however, research indicates that only up to 25 of these carotenoids are available and enter the human bloodstream [61]. The availability of carotenoids is influenced by several factors, including physical form of food and supplement matrix, dietary fibre content, processing treatments (such as heating), interaction with other nutrients, particularly dietary fats [62,63]. However, a double-blinded placebo-controlled trial known as the COAST study provided evidence that the bioavailability of L, Z and MZ can be enhanced when L, Z and MZ supplements are in a diacetates micromicellar formulation [35]. Importantly, L, Z and MZ are exclusively found in the macula of the retina in humans [48,64,65,66,67], underscoring their importance for eye health.

Humans and nonhuman primates possess a unique anatomical feature: the macula, which is located in the central part of the retina. This area, which accumulates the yellow macular pigmentation (MP), is commonly referred to as the "yellow spot" or macula lutea [68]. The concentrations of L, Z, and MZ (collectively, MP) in the macula is approximately 100 times greater than in other regions of the eye [69]. These cone-rich photoreceptors are vital for achieving the highest visual acuity, as they receive the most exposure to light within the retina.

There are several possible theories explaining the selective accumulation of XC at the macula. However, a study using an *in-vitro* model by Thomas and colleagues [70] demonstrated the mechanism most widely agreed upon. The study demonstrated that the Z appears to be more effectively delivered to retinal pigment epithelium (RPE) ARPE-19 cells by high density lipoprotein (HDL), via an SRB1-dependent process while L is delivered through low density lipoprotein (LDL) by an LDLR-dependent process [70]. The xanthophyll bound to lipoproteins transiently reaches the neural retina (photoreceptors), supplying nutrients (macular pigment)to the photoreceptor cells. A study conducted *in-vivo* and *in-vitro* systems showed that RPE65 catalyzes the formation of MZ from L in RPE and hypothesized that this MZ is transported into the subretinal space and then into retinal layers by means of transport proteins. In the retina, it is held in place in the foveal region, which is at the central part of the macula, by a specific binding protein [32,71]. Of note, recent work published by Bernstein et al. [72]. has revealed the existence of carotenoid-binding proteins within the photoreceptors of the monkey's foveal region and Henle fiber layer. These proteins play a crucial role in ensuring the specific distribution and stability of carotenoids within the foveal region [72].

At the foveal region, Z concentration is over 2 times higher than L, but diminishes with increasing distance from the fovea with a reverse ratio of 1:2 from Z to L [73]. Close to half of the Z in the macula comes from dietary Z and the other half comes from MZ [48], again pointing to the unique role of MZ within MP. The selective distribution within the macula suggests distinct properties and functions of these individual carotenoids.

## 4. Functional Properties of the Yellow Spot and Its Contribution to Vision

Light is composed of an electromagnetic spectrum extending from ultraviolet light (wavelength around 10–400 nm) to infrared light (wavelength around 780–1,000,000 nm). The human eye is sensitive to light wavelengths between roughly 380 and 750 nm (visible light), which are readily transmitted by the photoreceptors of the retina [74]. The exclusive presence of yellow pigment in the macula serves to protect this light-sensitive tissue from potential light-induced oxidative damage by acting as a short-wavelength light filter (i.e., 400–520 nm filtration band) [75,76] and by limiting photo-oxidation and physiological oxidation [30,36,37,38,77].

### *4.1 Antioxidant*

Lutein, Z, and MZ play an important role in the protection against light-initiated oxidative damage on this tissue, where excessive light exposure leads to retinal damage [30,36,37,38]. Oxidative stress can lead to tissue damage caused by reactive and unstable molecules, known as reactive oxygen species (ROS). These unstable molecules attack stable cells and destroy those cells [78]. Many studies suggest that ROS production can be reduced by antioxidants [79,80,81,82,83,84] through three possible mechanisms: oxidation, electron transfer, or hydrogen abstraction [49]. The ROS is produced when a photosensitizing compound or molecule (lipofuscin, protoporphyrin, or cytochrome) absorbs UV or short-wavelength blue light in the retina [85,86]. The retina is prone to oxidative stress (photo-oxidation) due to the high amount of polyunsaturated fatty acids (PUFA) at the outer segment membranes of the photoreceptors in the retina. This exposes them to oxygen tension, leading to the production of ROS [78]. The presence of hydroxyl groups in L, Z, and MZ makes them more hydrophilic, enabling them to react with oxygen in the liquid phase and more efficiently scavenge ROS. The MP efficiently absorbs and transmits excited energy, act as a potent scavenger of free radicals, and dissipates this energy as heat [49,86], reducing oxidative damage in the retina photoreceptors. The antioxidative properties of MP play a crucial role in protecting visual health from adverse effects of potential phototoxic light throughout the human lifespan [34,72,87,88,89,90].

### *4.2 Blue Light Filter*

As humans age, their eyes experience a decrease in scotopic (twilight vision) and shortwave sensitivity [91]. However, research has shown that a higher concentration of MP can help preserve shortwave and scotopic functions to some degree [92]. The shortest visible blue light (400 to 500 nm), which carries the highest energy, causes damage to the retina by inducing photo-oxidative stress, but also reduces visual function due to light scattering and other factors (explained below). MP absorbs about 40% of short wave-length blue light, with peak absorption at around 450 nm [76,77]. The light-absorbing characteristic, specifically filtering visible blue light, results in improving photostress recovery, reducing chromatic aberrations and glare discomfort, and scattering light ("veiling luminance"), thereby optimising contrast sensitivity. Junghans and colleagues [93] conducted a study investigating the blue-light filter efficiency of L, Z and two other carotenoids (lycopene and β-carotene) in liposomal membranes. They found that L and Z had the highest blue-light absorbing capability compared to other carotenoids. Additionally, the highest concentration of macular pigment is found in the outer plexiform layer of the fovea, which is believed to be an optimal location for shielding the outer retina from photo-oxidative damage [76]. A high intake of L and Z through diet or supplementation, including MZ, has been found to increase MP and to improve visual function in terms of glare disability, photostress recovery, chromatic contrast, and visual temporal processing speed (i.e., speed at which the brain perceives and makes sense of visual changes) among general population studies [30,36,37,38,94,95,96,97].

In the CREST study, Nolan and colleagues [95] discovered that contrast sensitivity at 1.2 and 6 cycles per degree (cpd) significantly improved with increased MP levels, following L, Z, and MZ supplementation in a healthy population. Having good contrast sensitivity greatly impacts how well one can see, as demonstrated by Owsley and Sloane's study [98], which showed that contrast sensitivity level influences the visibility of real-world targets. It has also been demonstrated that MP could enhance long-distance vision. Wooten and Hammond [99] discussed the impact of MP's absorption of short-wavelength dominant atmospheric light. They concluded that an individual with 1.0 log unit of macular pigment optical density (MPOD) could potentially see 26% farther through the atmosphere compared to someone with low or no MPOD. This effect has recently been tested experimentally and has been shown to closely align with the predicted increase in visibility in blue haze. Therefore, individuals with higher levels of MP could endure more light before losing sight of a target [99]. Recent data from our studies indicate that a daily intake of a formulation with a MZ:L:Z (mg) ratio 10:10:2 results in optimal circulation in serum carotenoids concentrations [100], enrichment of MP both centrally and spatial profile [56,100] and visual function enhancement in healthy retinal subjects [94]. Hence, by enhancing visual function in high-performing athletes through XCs nutritional supplementation, sport performance will likely improve in athletes that rely on visual function, such as precision sports.

## 5. Visual Characteristics in Precision Sports

"Normal eyesight", which determines the clarity of image on the retina, is defined as healthy with visual acuity of 20/20 for the non-athlete population by optometrists. However, there were consistent findings from many studies in sports, where athletes have demonstrated better visual acuity of 20/15 [6,18,101,102] or better (20/9.2) [20] than in nonathletes. Studies have highlighted that visual acuity is an essential visual function for shooters and archers [103,104]. A study by Junyent and Forto (1995) [105] further validated a finding that the worst shooters tend to present lower visual acuity and accommodative facility in their dominant eye. Nevertheless, recent studies and reviews have challenged this notion, emphasising that beyond acuity, visual memory [106], contrast sensitivity [7,107], and reaction time [108,109], fixation [9,107,110,111,112], ocular dominance [113] and eye-hand coordination [106], are important measurable visual functions categories that must not be underrated for peak sporting performance.

The "Vision Pyramid" (Fig. 1), proposed by Kirschen and Laby (2011) [114], was presented to ophthalmology, optometry, and athletic trainers at the sports vision meeting in 2010. This pyramid displays various components of visual characteristics in sports in a systematic approach. The tip of the pyramid is the "Best On-Field Performance", which is the ultimate goal of performance enhancement for all athletes. For this to happen, the foundation at the base, "Visual Acuity and Contrast Sensitivity", and all other supporting levels, need to be optimised. Another notion associated with the pyramid is that all levels can be improved, whether through optical devices (such as glasses or contact lenses), antioxidant supplements, or vision training [115].

The largest study investigating 387 baseball players' visual acuity and 364 players' contrast sensitivity levels, found that players' visual acuity was better than the normal population. Though there was no statistically significant difference in visual acuity between major and minor league players, 1% of minor league players have 20/9.5 or better acuity than major league players. Interestingly similar trend was not noticed with contrast sensitivity. Acknowledged as a limitation of the study, the major league players, despite having a smaller sample size, outperformed minor league players in several contrast sensitivity tests, 3.0 and 6.0 cpd [20]. This study interestingly demonstrates that athletes with good acuity, who were able to see objects in high-contrast backgrounds, may still struggle to see well if the contrast changes. Remarkably, the research by Nolan et al. [95] highlights the promising potential of carotenoids supplementation to enhance contrast sensitivity at 6.0 cpd in healthy individuals. This finding opens up opportunities to improve visual performance in the sports population through carotenoid supplementation [95].

### *5.1 Precision Sport: Shooting and Archery*

With regards to precision sports, such as shooting and archery, athletes frequently encounter figure-ground perception, which is the ability to differentiate an object amidst a busy and similar background [116]. This perception can be affected by exposure to the lighting on an object [117]. Good contrast sensitivity is said to be essential for skeet or trap shooting and archery. It helps athletes to distinguish orange-coloured targets against ground background such green or brown grass, foliage (trees), and sky (blue, cloudy, or heavy cast sky). This skill is crucial even in athletes with well-developed cognitive processing of visual information [104,115]. In the limited studies focusing on acuity and contrast sensitivity in target-based sports, Laby and colleagues [6] found that Olympic-level archers demonstrated superior visual acuity and contrast sensitivity at 18 cpd, as well as contrast with glare at 1.5 cpd, compared to athletes from seven other Olympic sports. Erickson (2021) [7] discusses the significance of eye dominance in "sighting" sports, such as target shooting, drawing on various studies [118,119]. Understanding and leveraging the alignment of eye and hand dominance can lead to improved skills acquisition and greater success in these sports. In this context, Abernethy and Neal [109] cited Lander and colleagues [120] study, which made a great effort to evaluate the nature of the skilled performance of elite and non-elite air rifle, air pistol, small bore rifle, trap and skeet shooters. They identified that acuity in the dominant eye at a

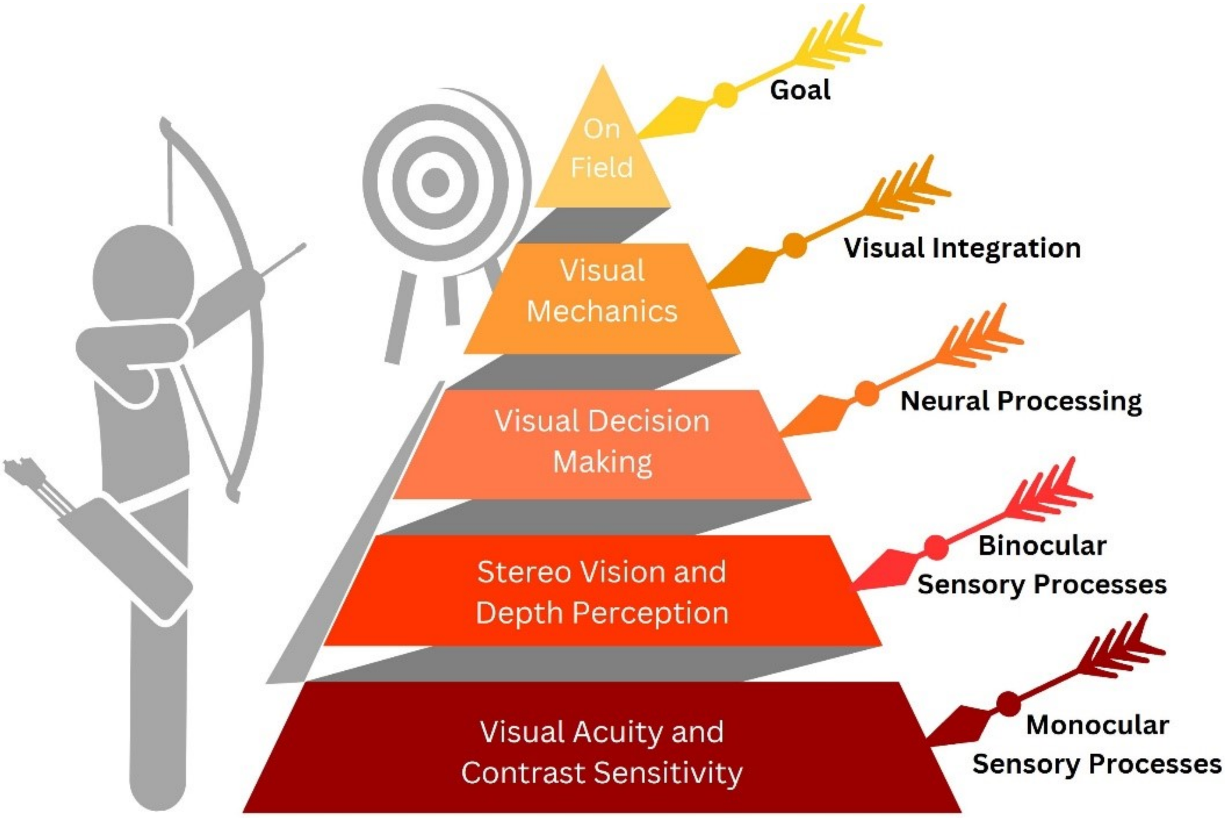


**Fig. 1. The sports vision pyramid**. Remodeled based on The Sports Vision Pyramid [114]. The pyramid illustrates the levels of various visual components that contribute to optimal sports performance. The base of the pyramid emphasizes the importance of enhancing basic monocular visual functions, specifically visual acuity and contrast sensitivity. If these foundational elements are not optimized, the binocular visual function of stereoscopic vision, represented in the next tier, will also be suboptimal. The subsequent tiers, which involve decision-making and appropriate motor reactions, heavily depend on the information processed from the first two tiers of the pyramid to achieve effective sports performance.

near distance is one of the important visual characteristics of a successful shooter. Additionally, a study that examined the visual acuity of Olympic pistol and rifle shooters agrees with this finding [103]. Shooters also displayed better visual acuity than non-athletes, despite having significantly older age athletes, above 29 years of age, than the non-athlete group. Allen and colleagues [121] aimed to determine the level of vision necessary for rifle shooting competition for Paralympic athletes. In this study, they tested 27 elite able-sighted shooters with good levels of habitual visual function with simulated glasses to reduce acuity and contrast sensitivity during shooting performance. Interestingly, the study found that athletes' shooting performance deteriorated with poor acuity and contrast sensitivity [121].

### *5.2 Precision Sport: Electronic Sports or Electronic Games*

Electronic sports (Esports) or electronic games (Egames), in contrast to traditional target sports, demand a unique skill set that can quickly switch tasks and respond rapidly to multiple visual and auditory cues. This dynamic environment fosters adaptability and sharp reflexes, making it a distinct and engaging form of competition [122]. Research by Li and colleagues [123] compared the contrast sensitivity function between expert video game players and non-game players. They found that expert video gamers have better contrast sensitivity compared to non-video game players [123]. Nevertheless, long duration of computer usage (≥4 hours/day) has been shown to decrease contrast sensitivity in computer workers compared to the control group (≤1 hour/day), though no changes in visual acuity were observed in either group [124]. Appendix Table 1 (Ref. [6,103,104,121,125,126,127,128]) illustrates studies exploring visual acuity and contrast sensitivity characteristics and their influence on sports performance in precision sports.

## 6. The Impact of Photo-Oxidative Stress on Vision in Precision Sports Athletes

In shooting and archery, light travels from the target and enters the eye, passing through the optical system, including the vitreous, and focusing at the back of the eye, at the retina. The information is then interpreted by the optical centre in the brain, which determines when to trigger a response [129]. Typically, these athletes train for about 2–3 hours for 5 to 6 times a week and compete for around 1.5 hours per session. They conduct these activities either in well-lit indoor 10-meter ranges or under natural bright sunlight in outdoor 25 to 50-meter ranges, depending on the time of day and scheduling of competitions.

As for Esports, athletes compete in virtual gaming at a professional level, either as a national or international competitors [130]. Concurrently, there exists a subset of players who engage in virtual games for leisure and recreational purposes, commonly referred to as Egames [131]. Based on the games played, two or more players compete equally for the same game, striving to outperform one another within the limited time frame. It is noteworthy that both categories of players often invest considerable time looking at screens on devices such as smartphones, tablets, and monitors of various sizes. Professional Esports athletes spend between 8 to 16 hours each day in front of a screen, usually in dimly lit gaming environments. In contrast, casual Egame players may spend less time gaming but are still exposed to considerable digital-screen time [130], and often play in varied lighting conditions.

In the realm of sports, there is ample documentation indicating that acute and strenuous bouts of intense sessions of aerobic and anaerobic exercise, or prolonged periods of exhaustive physical activity over multiple days, instigate reactive oxidative stress. This stress leads to oxidative damage in skeletal muscle and metabolically active organs [83,132,133]. In addition, these precision sports athletes are subject to prolonged and repeated exposure to light, around 400–440 nm short-wavelength blue light [85], for a few seconds to several hours. This exposure can occur either under the sun [134] or under the arc lamps, tungsten-halogen, lamp filaments, and light-emitting diodes (LED) [135,136]. The RPE and certain photoreceptors (rods and cones) cells in the eye can undergo photochemical damage due to the amount of exposure to the short-wavelength blue light. There is increasing research into how screen exposure affects Esport and Egame athletes' and players' eyes and vision [125].

Managing blue-light exposure is crucial not only for protecting the eyes from light damage but also for optimizing performance in precision sports. Maximum precision and accuracy are critical attributes to achieve high-level performance in Olympic shooting sport [137] and archery [104], which have similar visual demands [104] and performance outcomes. Technical elements such as: (i) the timing of triggering, (ii) the "cleanliness" of the trigger for shooters or release of string and arrow for archers, (iii) stability of hold, and (iv) aiming accuracy for both sports have been pinpointed as factors influencing shooting performance [111,138,139,140,141,142,143]. These four components account for up to 81% of the variance in shooting scores [144].

In activities like 10 m rifle shooting, accurately aiming at a stationary target requires the precise alignment of the eye with both the rear and front sights [145]. This alignment relies on visual perception, cognitive-perceptual abilities [146] and fine motor control [147] to execute perfect shots. For example, in 10 m rifle competitions, the target is positioned 10 m away, with a 10-point scoring area measuring 11.5 ± 0.1 mm for pistols and 0.5 ± 0.1 mm for rifles [145]. Therefore, the precision of movement and accuracy of visual information could prevent minute angular errors, which could potentially prevent scores below 10 points [148]. This level of precision is also relevant for elite Esport players, especially when multiple fast-moving visual targets appear that need to be shot or attacked quickly. The dynamic visual demands on these players' vision, combined with the increasing duration of training, put significant stress on their visuomotor abilities as they must rapidly perceive and respond to these stimuli. In these games, players are required to stay in one place and perform precise tasks such as navigating through scenarios, aiming, shooting, or attacking targets within a limited space. Players need to demonstrate both accuracy and speed, making quick reactions essential as they use a computer mouse or device to execute their "shots".

As mentioned, ineffective scattering of light can hinder. This visual demand becomes more pronounced in outdoor settings with varying weather conditions, such as shadows overlaying on cloudy days and glare on sunny days. Variations in lighting can challenge athletes to quickly adapt and maintain optimal visual performance throughout [7]. Supporting this idea, a study conducted by Shi et al. [149] explored the neural mechanisms involved in shooting preparation among skilled shooters, identifying that performance in low-light environments suffered significantly. Another study has demonstrated impacting slower reaction times in athlete population when the light diminishes as well [150].

We can argue that the visual demands of playing Egames/Esports are similar to precision sports like clay-pigeon shooting and skeet. In both cases, athletes and players must detect a target, aim and shoot in stationary position within a given time duration [9]. However, as previously emphasised, Esports and Egames athletes and players face greater challenges in reacting dynamically to several visual and acoustic stimuli. Thus, making quick and accurate decisions, as well as responding swiftly, is crucial to their performance [151,152]. Exposure to light from electronic devices can lead to visual disturbances for athletes and players in this sport. Our understanding of visual disturbances is informed by studies in eye care literature, which primarily focus on managing computer vision syndrome (CVS), such as glare, blurred vision, and increased sensitivity to bright light [124,153,154]. These symptoms have been observed in computer users, as highlighted in a study conducted on office computer workers in New York

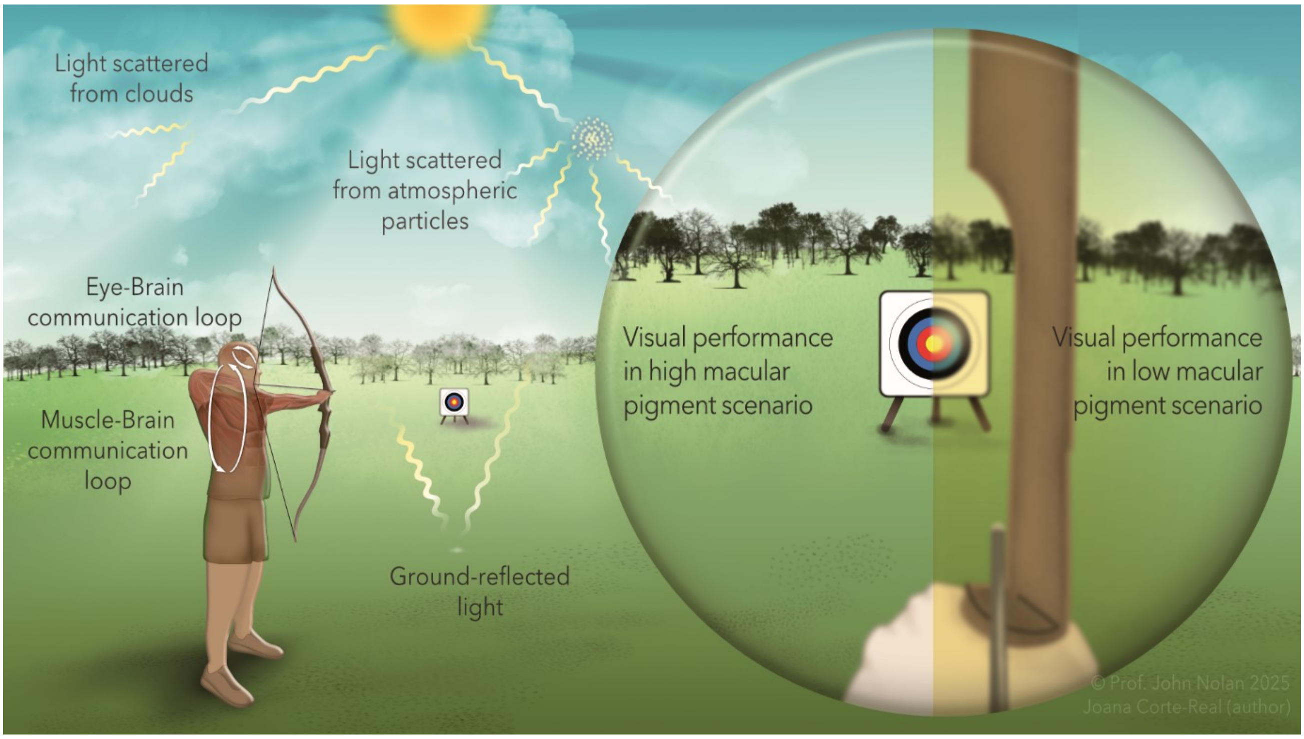


**Fig. 2. The influence of low and enriched macular pigment levels in an archer's visual performance during outdoor training or competition**. Illustration 1 summarises how low and enriched macular pigment levels influence an archer's visual performance during outdoor training or competition. The zoomed-in visual image on the right shows an archer with low macular pigment encountering various environmental challenges. These challenges include varying weather conditions, such as shadows overlaying cloudy days and glare due to light scattering from sunlight, clouds, and the ground, which significantly diminishes target visibility. This reduction in visibility adversely affects the interactions among the eye, brain, and muscles necessary for accurately aiming the target. Conversely, the left image depicts a hypothesis that with an enhanced macular pigment, the archer can mitigate such challenges effectively by filtering visible blue light and scatter. The enriched macular pigment contributes to improved recovery from photostress, reduced chromatic aberrations and glare discomfort, and decreased light scattering, all of which enhance contrast sensitivity.

(Portello et al., 2012) [155]. Notably, Chaiwiang and Kooakarakul's (2024) [125] study found that Thai Esports athletes had decreased visual acuity and other computer related symptoms compared to the control group, suggesting that these athletes have a higher risk of CVS than the control group. This is likely due to prolonged screen time, excessive light exposure, and high stress levels [125]. Prolonged use of these devices can lead to a reduction in optical quality, as well as dry eyes and decreased blinking, all of which negatively impact the visual acuity and contrast sensitivity [124].

Of note, many athletes commonly employ measures such as visors or caps, opt for tinted glasses or sights [145] and optimising ambient lighting or filters to reduce blue light exposure [156] to mitigate the impact of glaring light on their vision, ensuring a clearer visual experience, including to protect eye, during their sport. A review by Kohmura (2021) [134] suggested that research on the effectiveness of tinted glasses, such as sunglasses, and their usage guidelines has not been reviewed for at least 35 years. Numerous studies suggest that yellow-lensed sunglasses, which filters blue-light, are effective in improving contrast sensitivity and brightness [3,157,158,159,160]. However, Kohmura et al. [161] reported that colored lenses; such as light and dark yellow, light and dark grey, may not adequately block off glare in the daylight function in sports population. Erickson et al. (2009) [162] found other coloured contact lenses, such as grey-green, can improve low-contrast visual acuity in bright sunlight. In outdoor target sports, shooters use telescopic sights, and archery employ to aiming scope with tints for clarity and accurately align their targets without the need for near accommodation [115]. Although wearing these visual aids offer clear benefits, some athletes may choose not to use them due to unstable vision, movement of contact lenses affecting contrast sensitivity [163], lens fogging and precipitation on spectacles due to environmental conditions [164]. It is also worth noting that these eye and head gears do not protect their eyes from oxidative damage caused by the light. Additionally, we are unaware of the impact on performance for light exposure incurred outside of training and competition. It is possible that exposure of bright light prior to competition could impact performance; however, there is no research that we are aware of that supports this notion. However, as mentioned in Section 4 above, the macular carotenoids are uniquely positioned to support the athlete's vision relevant to all these challenges.

## 7. Additional Boost to Brain Function in Precision Sports

It is also worth noting that the eye is an extension of the neural system and the presence of MP in the retina and brain selectively [65,165] indicates a distinct synergistic relationship between them. Studies have found that the brain tissue contains macular carotenoids and omega-3 fatty acids [166,167] and that carotenoids in the brain are related to retinal carotenoids [168]. Feeney et al. [169] discovered a positive connection between plasma levels of L and Z and performance in three cognitive areas: global, memory, and executive function. They also found a notable link between Z and the processing speed composite score in 4076 adults living in the community as part of the Irish Longitudinal Study on Ageing [169]. Higher dietary intake of L and Z, as well as increased serum levels of L and Z, have been linked to improved cognitive function. This includes faster temporal processing in younger individuals [170], improved visual-motor response in healthy adults [171] and slowing the progression of neurodegenerative disease [172]. Augmenting levels of L and Z may influence cognitive function, which could impact daily cognitive function in the general population and be advantageous for optimizing sport performance in the athlete population. For example, motor skills such as eye-hand coordination and reaction rate are important aspects in precision sports [103,104,126,130].

Li et al.'s [173] review advises against placing a blue light filter within intraocular lens. Blue light is essential for activating the rods located in the peripheral retina, which contributes to low-light vision. Instead, incorporating macular carotenoids in the central retina can enhance central vision by reducing issues related to blue light scatter and chromatic aberration. This approach also ensures that the non-central retina receives the short-wavelength light necessary for vision in dim conditions [173]. As such, we acknowledge that filtering reduces the exposure to blue light, which can improve retina health and enhance retinal performance in varying light conditions. We believe that implementing light filtration at the macula will provide more customized and optimised light filtration in the areas where blue light causes the most problems for visual performance (Fig. 2), illustration 1 demonstrates our hypothesis.

## 8. Conclusion

Vision and visual processing are acknowledged as critical components of successful athletic performance. Former football coach Blanton Collier is credited with the quote, "The eyes lead the body", underscoring the significant role that vision plays in guiding performance [174]. To enhance visual function, it is imperative to conduct a thorough evaluation of the factors that contribute to specific sports tasks. Common strategies for optimizing visual performance include glasses, contact lenses and sunglass [7,162]. With that said, we are seeing an increase in the use of nutrition for improving visual performance [41,42]. Although current research examining the effects of dietary supplements such as L, Z, and MZ on visual performance in healthy populations has not been extensively applied to sports, particularly precision sports, it presents a valuable area for exploration. While this article is not intended as a critical review of evidence-based research, it offers a summary of existing published studies in an attempt to illustrate the effectiveness of targeted nutrition on visual function in sports. This review's limitation is that it focuses on the vision element. Further work should connect the vision and cognitive elements, as we provide limited information in this review. The ongoing randomized controlled trial Sport Nutrition Intervention in Performance Exercise (SNIPE) is a novel research study that will provide an in-depth understanding of the impact of these interventions on sports.

## Abbreviations

cpd, cycles per degree; Egames, electronic games; Esport, electronic sports; HDL, high density lipoprotein; L, lutein; LDL, low density lipoprotein; MP, macular pigmentation; MPOD, macular pigment optical density; MZ, meso-zeaxanthin; RPE, retinal pigment epithelium; ROS, reactive oxygen species; XC, xanthophylls; Z, zeaxanthin.

## Author Contributions

PS and JN designed the review structure. FH, JS, and RS provided help and advice on visual performance and sports performance content. PS wrote the manuscript with supervision from JN. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

## Ethics Approval and Consent to Participate

Not applicable.


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## Conflicts of Interest

Professor John Nolan and Fraser C Horn performs consultancy activities via his company NOW-Science con-

**Table 1. Studies exploring visual acuity and contrast sensitivity characteristics and their influence on sports performance in precision sports.**

| Author/year | Sports | Age (Yrs) | Sex (Male/Female) | Study type | Aim of study | Measurement of visual function (VF) and sport performance (SP) | Static visual acuity (VA) | Contrast sensitivity (CS) | Sports performance |
|---|---|---|---|---|---|---|---|---|---|
| Mon-López et al., (2022) [103] | Shooting (Olympic air pistol and rifle) | 17 to 54 | 33/33 | Pre-Post | To understand the effects of eye strain on visual abilities before and after stimulated shooting competition by sport level. | VF: Sloan letter test for VA. SP: Wayne Saccadic Fixator device for eye-hand coordination. | Binocular VA was higher for elite and non-elite shooters (mean 1.34 ± 0.26 and 1.54 ± 0.24 LogMAR, respectively) than for non-shooters. | Not assessed. | Eye-hand coordination improved among both elite and non-elite shooters. |
| Guo et al., (2024) [126] | Shooting (Skeet) | 19.7 to 30.5 | 10/10 | Intervention | To explore the visuomotor abilities and shooting performance of skeet shooters through Sports Vision Training. | VF: Senaptec Sensory Station assesses VA and CS. SP: Senaptec Sensory Station measures eye-hand coordination. 60 shots was obtained for hit accuracy. | No differences observed. | Shooters (experimental and control groups) achieved elite performance with CS score of ~2.0 from the athlete's visual capability indicator (Senaptec database). This ranges between mean 1.99 to 2.16 LogCS at 6 cpd. | The experimental group improved in eye-hand coordination and hit accuracy with training. |
| Allen et al., (2018) [127] | Shooting (Rifle) | 17 to 56 | 14/13 | Experimental | To determine the impact of VA and CS impairment affects shooting performance. | VF: ETDRS LogMAR letter used for VA and Pelli-Robson chart used for CS. SP: Scatt system for shooting scores. | Greater reduction of VA (< –0.14–1.6 LogMar) decreases shooting performance. | A greater reduction in CS at 1 cpd (< 1.95– 0.0 LogCS) shows a more substantial decrease in shooting performance. | Reduction in VA and CS decreases the shooting score. |
| Allen et al., (2016) [121] | Shooting (Rifle) | 17 to 45 | 9/10 | Experimental | To determine the level of visual impairment that would decline shooting performance. | VF: ETDRS LogMar letter used for VA and Pelli-Robson chart used for CS. SP: Scatt system for shooting scores. | Moderate reduction in VA (<0.5 LogMar) shooting performance. | Moderate decrease in CS at 1 cpd (<0.8 Log) impact shooting performance. | A moderate decrease in VA and CS decreases the shooting score. |

**Table 1. Continued.**

| Author/year | Sports | Age (Yrs) | Sex (Male/Female) | Study type | Aim of study | Measurement of visual function (VF) and sport performance (SP) | Static visual acuity (VA) | Contrast sensitivity (CS) | Sports performance |
|---|---|---|---|---|---|---|---|---|---|
| Jamara et al., (2008) [128] | Shooting (Target Shooting Marksman) | 67 | 1 | Case Study | To shows how sports vision and low vision rehabilitation techniques can improve the visual function of a competitive shooter. | | A decrease in VA (0.03 LogMar, 6/6.5, or 20/21.4) impacts performance. | Decrease in CS (1.7 Log) hinders to see sight through telescope. | A decrease in VA and CS impacts sports performance. |
| Strydom, (2010) [104] | Archery (Compound and Recurve) | 12 to 58 | 21/7 | Cross-sectional observa-tional | To determine the most important visual skills and appropriate norms used in archery. | VF: Snellen chart used to assess VA and the Functional Acuity Contrast Test for CA. | Suggest VA is important skills as majority have achieved VA value 1.0 LogMar. | Suggest CS is an important skill due to the connection between VA and CS. | Authors propose that VA and CS are important visual skills in archery. |
| Laby et al., (2011) [6] | Archery (Olympic level with seven other sports) | 15 to 19 | 8/5 out of 72/85 | Cross-sectional observa-tional | To describe and understand the differences in the visual functions of eight Olympic-level sports. | VF: PSVTS by M&S Technologies was used to test VA (Londolt ring) and CA (Kandolt ring and Grating contrast. | Comparable good VA for archers (Right = –0.235 ± 0.113, Left = –0.204 ± 0.118) LogMar with other sports. | Demonstrate a high level of CS (0.492, ± 0.240 Log) and (0.400 ± 0.000 Log) at 1.5 cpd and 6 cpd spatial frequency with glare source, respectively, compared to other sports. | Authors propose that VA and CS are important visual skills for archery. |
| Chaiwiang & Koo-akarakul, (2024) [125] | Esport | 20 to 35 | 160/0 | Cross-sectional descriptive | To examine ocular and visual characteristics and enhance the visual health of Esport. | VF: ETDRS LogMAR letter used for VA and Pelli-Robson chart used for CS. | Esports athletes have lower VA (mean = 0.013 ± 0.043 LogMar) than the control group. | Not assessed. | Prolonged digital exposure disturbs ocular moisture balance and decreases VA. Indirectly affecting performance. |

Some of these studies also reported other outcomes. cpd, cycles per degree; Esport, electronic sport.

sultancy limited for companies selling food supplements containing the bioactives of the subject matter of this review. Professor Nolan is also a shareholder of Supplement Certified limited, a third-party supplement analysis company. Dr Fraser Horn does consultancy activities via Sports Vision Pro for nutraceutical companies. Dr James Stringham is employed by MacuHealth LP™, company selling carotenoids and omega supplements. The remaining authors declare no conflicts of interest. However, these companies had no role in the handling or conduct of the study. The author(s) had full access to all data in the study and take full responsibility for the integrity of the data and the accuracy of the data analysis. John Nolan is serving as Guest Editor of this journal. We declare that John Nolan had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to Torsten Bohn and Haixia Yang.

## Declaration of AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used Grammarly in order to check spelling and grammar. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

## Appendix

See Table 1.

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