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Key words
- visual field
- automated perimetry
- retina sensitivity
- soccer players

Abstract

The purpose of the study was to compare the peripheral retinal sensitivity of the visual field between professional soccer players and age-gender matched non-athlete subjects. All participants underwent a complete eye evaluation. The visual field was evaluated with the achromatic program 60–4 from the Humphrey automated perimetry. The binocular visual field was created with the *best location model*. It was divided into 4 quadrants (left superior, right superior, left inferior, and right inferior) and compared between groups. The study group comprised 29 professional male football players and the control group comprised 26 age-matched male non-athletes. Mean age was 25.8 ± 4.7 years in the study group and 26.3 ± 5.1 for controls. The average of retina sensitivity in the left inferior and right inferior quadrants was higher in the study group (27.2 ± 1.2 dB and 27.0 ± 1.4 dB) as compared to controls (26.1 ± 1.9 dB and 25.5 ± 2.1 dB). (Student's *t* test, $P = 0.011$ and $P = 0.004$, respectively). In this small cohort, professional soccer players presented higher retina sensitivity in the inferior quadrants when compared to non-athletes.

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The visual field is the spatial array of visual sensations available to observation in introspectionist psychological experiments [21]. It refers to the total area in which objects can be seen with the peripheral vision while one focuses the eyes on a central point. The normal human visual field extends to approx. 60 degrees nasally from the vertical meridian in each eye, to 100 degrees temporarily from the vertical meridian, and approx. 60 degrees above and 75 below the horizontal meridian [22].

The issue of peripheral vision on athletes' sports performance has been a topic of discussion for many years. Tergerson found that badminton players of high skill level had superior peripheral vision, suggesting a relationship between skill level and peripheral vision [24]. Lee and Lishman theorized that peripheral vision provided continuous input that influenced balance via minute muscular corrections [15]. Previous studies have verified that sports players have wider visual fields as compared to non-athletes. Mizusawa et al. examined effects of sports practice on patterns of color fields, limits of peripheral movement perception, and visual acuity field by comparing varsity ball players and non-varsity controls. They noted that athletes had wider limits for horizontal movement perception, and that basketball players demonstrated color fields and limits for peripheral movement perception superior to those of soccer players [18]. According to Stine et al., the literature shows that athletes have larger extent of visual fields, larger fields of recognition (peripheral acuity), larger motion perception fields, lower amounts of heterophoria at near and far, more consistent simultaneous vision, more accurate depth perception, better dynamic visual acuity, and better ocular motilities [23].

More recently, Ludeke and Ferreira evaluated the difference in the visual skill level of professional vs. non-professional rugby players. The software visual skills, involving skills such as eye-hand coordination, eye-body coordination, central-peripheral awareness, and reaction time were examined. Although the results indicated that the professional players did outperform the non-professional players on all these skills except for visual concentration, not all the results achieved statistical significance [16]. Muinõs and Ballesteros investigated the peripheral vision and perceptual asymmetries in young and older martial arts athletes. Using dot stimuli presented at 3 different eccentricities along the horizontal, oblique, and vertical diameters and 3 interstimulus intervals, the authors showed that karate athletes performed significantly better than non-athletes when stimuli were presented in the peripheral visual field [19].

Except for the latter 2, most studies are relatively old and, since then, new technologies have emerged, and new ways to evaluate the visual function have been developed. Automated perimetry is the current gold standard method to evaluate visual fields in glaucoma patients and neurological diseases. Static perimetry is able to detect the retinal sensitivity in different test points of the visual field and quantitative measurements such as the mean deviation and pattern standard deviation provides a more detailed appraisal of the visual field. Hence, the purpose of the study was to compare the retinal sensitivity of the peripheral visual field of professional soccer players and that of an age-gender matched non-athlete controls using automated perimetry.

Materials and Methods

This was a cross-sectional study and participants were enrolled consecutively. The Institution Ethics Committee approved the study, and all of the subjects signed an informed consent. The procedures followed adhered to the principles for medical research involving human subjects of the Declaration of Helsinki in 1964 (amended by the 59th WMA General Assembly, Seoul, Korea, October 2008) and the Ethical Standards in Sport and Exercise Science Research [13]. Professional soccer players of the Goianiense Athletic Club, currently in the second division of the Brazilian Football Federation league were invited to participate in the study. The evaluations were conducted at the Panamerican Institute of Vision which serves as a backup eye care center for the Club.

Sample and inclusion criteria

In order to be included in the study, all participants had to be male, between 18 and 35 years of age and the general eye examination could not indicate any abnormality according to the following parameters: best-corrected visual acuity higher or equal to 20/25 on both eyes; external examination demonstrating round and reactive pupils; external ocular motility without any ocular deviation (strabismus); biomicroscopy using slit lamp showing clear corneas, normal irises, no lens and/or vitreous opacities; fundus showing optical disc with sharp edges, cup-to-disc ratio equal or less than 0.3 on both eyes, normal retinal pigment epithelium; intraocular pressure ≤ 21 mmHg measured with the Goldmann aplanation tonometer; a reliable visual field test (see below); and no previous eye surgery.

29 professional soccer players were included in the study. The mean age was age was 25.8 ± 4.7 years (range 18–35 years). As to ethnicity, 13 were white (45 %), 7 African-Brazilian (24 %) and 9 were mixed (31 %). All players had at least 6 years of soccer practice, starting at age 14 years at soccer academies or U 17 (under 17 years of age) professional soccer clubs.

The control group comprised volunteers, non-athletes who fulfilled the inclusion criteria. Physical and sports activities practiced as leisure or in an amateur fashion were allowed. 26 subjects enrolled as controls. The mean age was age was 26.3 ± 5.1 years (range 18–35 years). As to ethnicity, 15 were white (45 %), 4 African-Brazillian (24 %) and 7 mixed (31 %). The sample demographics are depicted on **Table 1**.

Table 1 Demographic characteristics of all participants.

	Study group	Control group	*P*-value
Age *	25.8 4.7	26.3 5.1	0.875
Gender (M:F)	29: 0	26: 0	0.832
Ethnicity			
White	13	15	
African-Brazilian	7	4	0.621
Mixed	9	7	

* mean ± standard deviation M: male F: female

Procedures

The ophthalmic examination was done by one of us and included visual acuity with and without optical correction, according to the Snellen and Jaeger chart; static and dynamic refraction, with static done after the visual field; biomicroscopy of the anterior segment of the eye with the Topcon slit lamp SL-3 (Topcon Corporation, Tokyo, Japan); indirect ophthalmoscopy with Topcon ophthalmoscope (Topcon Corporation, Tokyo, Japan) and a converging 20 D lens (Volk Optical Inc., Ohio, USA); aplanation tonometry with Goldman tonometer, coupled at the slit lamp, after topical instillation of proximetacaine hydrochloride and sodium fluorescein.

The visual field examination was done by a trained technician using the Humphrey automated perimeter (HFA 750, Carl Zeiss-Humphrey, Irvine, CA, USA), peripheral 60-4 threshold test program, SITA-fast (Swedish interactive threshold algorithm) strategy. In brief, the participant was placed facing the perimeter's white concave dome (background lighting of 31.5 abs), while holding a button, and the eye that was not being tested was covered. All participants were instructed to keep looking at the target point and click the button every time he noticed a light, either bright or dim. The standard luminous stimulus was 4 mm^2 large and presented for 0.2 s. First, the right eye was tested and, after a few minutes of rest, the left eye was tested. At the examiner's discretion, if any deviation from adequate performance test was noted, the exam was interrupted and new instructions were given in order to get a reliable test. A reliable visual field test was defined as loss of fixation of up to 20 %, false positive up to 33 % and false negative rate of up to 33 %.

Visual field analysis

The Humphrey peripheral 60-4 threshold test program provides a monocular test of 60 points of the visual field between 30 ° and 60 ° degrees of visual angle. For each test point the program calculates the threshold of differential light sensitivity or the retinal sensitivity in decibels (dB). In order to predict the binocular retinal sensitivity we used the *best location model* [5]. The method is based on the highest sensitivity between the eyes at each visual field location integrating the corresponding visual field quadrants of each eye, resulting in a unique integrated (binocular) visual field. The binocular visual field is then a composite of the more sensitive of the 2 visual field locations for each eye. Each test point in the superior temporal quadrant of the right eye (RE) with a corresponding test point in the superior nasal quadrant of the left eye (LE) produced the binocular right superior quadrant Q1. Each test point in the superior nasal quadrant of the RE was compared to a corresponding test point in the superior temporal quadrant of the LE to create the binocular left superior quadrant Q2. Each test point in the RE inferior nasal quadrant with a corresponding test point of the LE inferior temporal quadrant generated the binocular left inferior quadrant Q3. Last, each test point in the RE inferior temporal quadrant with a corresponding test point in the LE inferior nasal quadrant formed the binocular right inferior quadrant Q4 (▶ **Fig. 1**). The mean sensitivity of each quadrant of the binocular visual field was calculated and compared between the study group and controls using the paired Student's *t* test with statistical significance set at 5 %.

Results

▶ **Table 2** depicts the mean retinal sensitivity of each of the 4 quadrants of the right eye visual field per group. The right inferior nasal quadrant of the soccer players revealed higher sensitivity than non-athletes (18.84 ± 3.29 dB and 16.32 ± 3.5 dB, respectively; $P = 0.008$).

▶ **Table 3** shows the mean retinal sensitivity of each of the 4 quadrants of the left eye visual field for both groups. The left inferior nasal quadrant of players presented higher sensitivity as compared to non-athletes (18.73 ± 3.49 dB and 16.58 ± 3.88 dB, respectively; $P = 0.03$).

▶ **Table 4** displays the mean retinal sensitivity of each of the 4 quadrants of the binocular visual field for athletes and non-athletes. Both the inferior left (27.29 ± 1.18 dB) and the inferior right (27.09 ± 1.44 dB) quadrants of the soccer players had higher sensitivity than non-athletes (26.10 ± 1.97 dB and 25.58 ± 2.15 dB, Q3 and Q4, respectively). Although small, the difference achieved statistical significance ($P = 0.011$ and $P = 0.004$, respectively).

Discussion

The results of this study concur with previous reports that athletes have better visual skills, especially with regard to better peripheral visual acuity and increased perception of visual field [23]. The visual field testing with the Humphrey automated perimetry is a surrogate way to evaluate *central-peripheral awareness*, i. e., the ability of the athlete to maintain central fixation on a target, yet be aware of what is happening to the sides or in the peripheral visual field. This is a function of visual perception and evaluates the athlete's ability to respond to central and peripheral stimuli without moving the head; it is usually investigated with the Acuvision 1000 [16]. It is important to note that none of the participants in this study had any experience of specific visual training or previous experience with automated perimetry, since a learning effect is a well-known feature of automated perimetry.

The subject's threshold of differential light sensitivity at each test location under the given test conditions (background luminance, stimulus size, etc.) is defined as the stimulus luminance, which is perceived with a probability of 50 % [27]. However the determination of retinal sensitivity involves not only the measurement of the visual function but also the perception of an image and the consequent motor reaction. During the visual field the participant was instructed to push a button every time he perceived the light stimulus. This means that the perception

Table 2 Comparison of the automated perimetry mean retinal sensitivity for right eyes.

	Study group	Control group	*P*-value
Superior nasal	16.2 ± 4.1	15.5 ± 3.9	0.577
Superior temporal	22.1 ± 2.2	21.2 ± 2.7	0.172
Inferior nasal	18.8 ± 3.3	16.3 ± 3.5	0.008
Inferior temporal	26.5 ± 2.1	24.7 ± 4.6	0.066

Table 3 Comparison of the automated perimetry mean retinal sensitivity for left eyes.

	Study group	Control group	*P*-value
Superior nasal	22.4 ± 1.7	21.5 ± 2.3	0.093
Superior temporal	17.2 ± 5.2	16.4 ± 2.4	0.506
Inferior nasal	26.9 ± 2.1	25.9 ± 2.0	0.113
Inferior temporal	18.7 ± 3.5	16.6 ± 3.8	0.034

Table 4 Comparison of the automated perimetry mean retinal sensitivity of the integrated (binocular) visual field.

	Study group	Control group	*P*-value
Right superior	23.2 ± 1.8	22.1 ± 2.3	0.072
Left superior	22.8 ± 2.1	21.8 ± 2.6	0.142
Left inferior	27.3 ± 1.2	26.1 ± 1.9	0.011
Right inferior	27.1 ± 1.4	25.6 ± 2.1	0.004

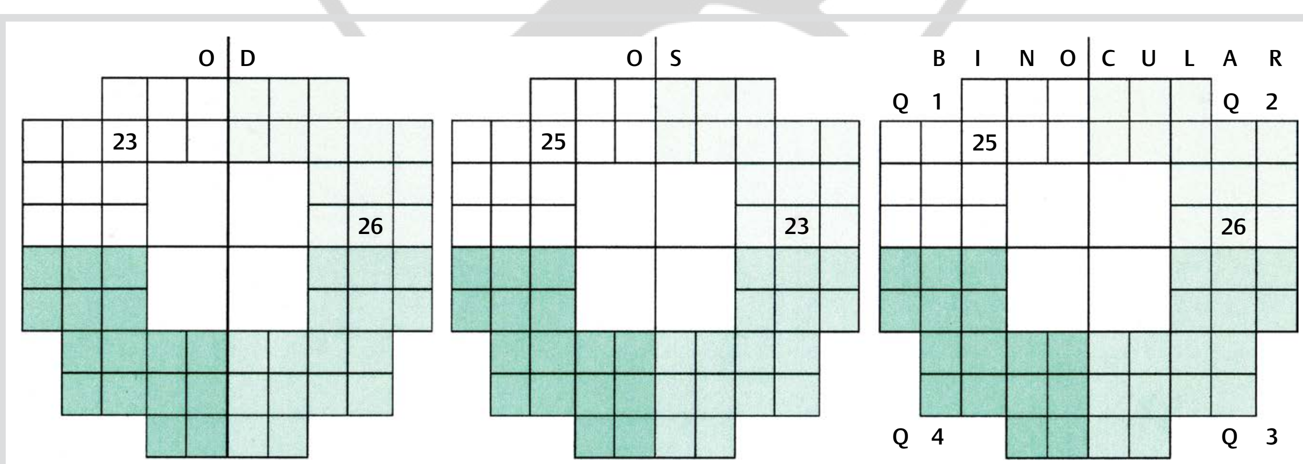

Fig. 1 Schematic representation of the integrated (binocular) visual field. Corresponding test points from the right (OD) and left (OS) eyes are compared and the more sensitive of the 2 locations is selected for binocular sensitivity.

of the light stimulus (afferent reflex) must be interpreted in the cerebral cortex triggering the motor action of hitting a button (motor reflex). It may be similar to another visual skill used in sports science known as *eye-hand coordination*, which involves the integration of the eyes and the hands. In other words, this determines the effectiveness of a perceptual motor response to a visual sensory stimulus [16]. Thus, the determination of the visual field involves the evaluation of complex mechanisms that go beyond the simple measurement of the sensitivity threshold. Therefore, athletes with higher retinal sensitivity not only have better retinal sensitivity, but also better sensory/motor function compared to non-athletes. In fact, Zwierko states that a higher level of visual perception in athletes is more related to recognition speed and responsiveness to stimuli than to the functioning of the visual system in the peripheral field [28].

The mean retinal sensitivity was higher in the lower hemifield of soccer players and that might be related to the unique feature of the sport. Soccer has become a complex and multi-dimensional sport. According to soccer practice and regulations, the arms and hands cannot be used to touch the ball. Inferior limbs are mostly used to kick the ball to the goal, to pass it to teammates and to dribble opponents. The ball as a visual stimulus is most of the time on the court ground and players are focusing it; at the same time they have to use their peripheral visual field to notice any approaching adversary and others teammates. These features might explain, to some extent, why the inferior hemifield is more sensitive in soccer players. Du Toit assessed the depth perception, accommodation flexibility, eye tracking, eye jumps, peripheral awareness and visual memory of 48 soccer players aged 12–20. The results indicated that visual skills tend to improve with age and that different positions do not necessarily require different levels of visual skills [7].

The results of our study can be explained in terms of perceptual learning. Perceptual learning is an increase in the ability to extract information from the environment, as a result of experience and practice with stimulation coming from it [8]. It has been involved in a number of sensory tasks, such as, visual acuity, hue discrimination, and 2-point somato-sensory acuity. Improvement in visual performance with repeated trials has been observed for a number of visual submodalities, including acuity, stereo-acuity, texture, motion, and orientation. There is reason to believe that learning can be seen for any visual attribute [9]. A number of studies have found evidence of perceptual learning for college-age subjects; however, some form of neural plasticity must exist well into adulthood, since visual performance can be improved even among older individuals [2]. In our study the oldest athlete was 35 years old. In terms of functional anatomy, our results suggest that learning involves experience-dependent changes at a level of the visual system where monocularity and the retinotopic organization of the visual input are still retained and where different orientations are processed separately. These results can be interpreted in terms of local plasticity induced by retinal input in early visual processing in human adults, presumably at the level of orientation-gradient sensitive cells in primary visual cortex [14].

The increased ability of top athletes to engage in sports practice and daily common tasks is the result of extensive exposure to repetitive training. Magnetic resonance images show that athletes have a significantly increased cortical thickness in specific areas of brain involving visual system capacities [26]. Besides, in athletes the experience-dependent learning and brain plasticity could level the differences of cognitive skills correlated to the sport type [20].

Athletic training is often accompanied by high activation of the visual system, especially in sports that require the processing of dynamic visual information, such as soccer. Ball sport players must process and integrate complex visual information, including the ball trajectory and kinetic position of their opponent and teammates. In many dynamic reactive sports, for instance tennis or volleyball, the speed of detection and discrimination of visual stimuli is a crucial factor in executing successful motor responses. Given the critical importance of dynamic visual input in team sports, one might predict that good performance in elite athletes might be supported by neuroplastic changes in early sensory processing [29]. Zwierko et al. investigated the effect of participating in volleyball training on the bioelectric function of the visual pathway in athletes and non-athletes. They examined early sensory processing with the use of VEP as tool for studying the cortical mechanisms of visual perceptual processing in 11 young female volleyball players who participated in extensive training for 2 years and compared to an age-matched female students who were not involved in any regular sports activity. Extensive experience with volleyball training reduced signal conductivity time through visual pathway. Specifically, the latency of P100 was reduced on average by 2.2 ms during binocular viewing [29]. These results imply that athletes have greater development of their ability to process visual information rapidly and reflect faster neural signal transmission in the optic nerve. The authors believe that modulation of visual processing might be the result of the specific requirements for a given sport training, in particular, the modulation of early sensory processing seems to be evident in athletes involved in ball sports requiring rapid responses to visual stimuli. Besides, they suppose that an expertise gained from participating in systematic exercise that demands a high level of visual attention during fast motor responses to external stimuli. Volleyball and soccer are dynamic reactive sports that require the processing of dynamic visual information. Given similarities between these 2 sports, the same mechanism Zwierko et al. propose to enhance visual ability in volleyball players might be applicable to soccer players to some extent.

In addition, other possible mechanisms can be involved as well. The post-training changes in the peripheral visual field can reflect the hypotheses that spatial attention in humans is associated with delayed feedback to area V1 from higher extrastriate areas that may have the function of improving the salience of stimuli at attended locations [6]. Perhaps, alternatively, it may be the result of feedback mechanisms exerted on primary visual cortex by influences from later visual processing stages [17]. It is reasonable to believe that the mechanisms underlying post-training visual processing are similar to those observed by perceptual learning.

The visual system can be compared to a computer system, in which there is a search and processing [1] modality. The visual performance in sports is the interaction between 2 visual systems. Sports psychologists separate the skills of the visual system into 2 components, hardware and software systems. In sports performance, the hardware components of vision are the non-task specific abilities such as ocular health, visual acuity, accommodation, fusion and depth perception. The software or cognitive aspects include visual perception, visual concentration, visual reaction time, central-peripheral awareness and visualization and it is these cognitive aspects that distinguish experts from novices [10].

Motor actions are basically accomplished by 2 different mechanisms, the afferent (receiving) and the efferent. The first one encompasses the visual system that receives information from the environment and the brain that responds to the appropriate signals sending them to the efferent mechanism. The second refers to the motor system, which responds to the signals from the brain to make the right responses. The visual system gathers information from the environment and the situation. A professional competitive game demands a very high performance from the human body, both physically and mentally. The stress put on the human body obstructs the receptors, including those from the visual system. This, in turn, compromises the motor responses. Besides, the electric sensitivity of the eye diminishes under conditions of physical strain and exercise at high workloads and cerebral hypoxia has detrimental effects on the ability to respond to peripheral visual stimuli [12–4]. These are normal stress factors during a game which can restrict the athlete's visual function and his best performance.

Visual reaction time is another cognitive function of the visual complex software. It is termed as the time required to perceiving and responding to a visual stimulation. The Wayne's saccadic fixator is used to measure the speed that an athlete can move his hand through a distance of 0.72 meters. This test determines how quickly an athlete can move his hand through a given distance and eliminates the influence of central-peripheral awareness. Ando et al. proved that the central and peripheral visual reaction time of soccer players is significantly shorter than that of non-athletes. Their results suggest that soccer players are better able to respond quickly to a stimulus presented to both their peripheral and central visual fields [3]. In our study, we found that the average time for the exam in each eye in the group of athletes was 4.08 min and in the group of non-athletes was 4.48 min, suggesting better reaction time in the athletes group. However, the Humphrey visual field analyzer is not a test to evaluate visual reaction time.

The body alarm reaction (BAR) is defined as the response of the human body to an unexpected and sudden change in the environment or a type of stress caused by the body's response to a stronger than normal stimuli or stressor agents. When an athlete enters into the BAR, a series of neural and biochemical reactions cascade into action. The accommodation system loses its ability to maintain clear focus on close targets and the athlete's visual attention is drawn to focus towards infinitum. This accommodative shift is a direct result of the change from parasympathetic to sympathetic nervous system control and can be correlated with a behavioral shift from central (detailed) visual attention to peripheral (global) visual attention [11]. Stronger than normal stimulus and stressor agents are quite common in a soccer match, so that BAR do occur in athletes during the game. This study was conducted immediately after the players' vacation, during the pre-season at which time they were relaxed with no tension or stress different from situations experienced in championship games. The best retinal sensitivity in the lower visual field of the athletes seems to be an acquired characteristic that is incorporated into the visual function even when they participate in other than sportive activities.

The study has some shortcomings. The sample size was relatively small and included only men. However, the study was conducted during the pre-season, and not all players had presented to the club at that point. It would most certainly be interesting to evaluate if the increased retinal sensitivity is gender specific, since cognitive capacity could be influenced by the sport type and by sex [25]. However, the club has only male players, as it is not part of the Women's Soccer League. When evaluating the visual field, each eye was tested separately and then integrated using the best location model. This might have caused the second eye to outperform the first one as a result of learning effect. Nonetheless, we did not find this to have biased the results of the study since all participants, both study group and controls, underwent the same procedure. The HFA has strategies to test both eyes simultaneously, yet these are screening strategies, and they do not measure the retinal sensitivity at each test location.

In summary, this study revealed that football players have higher retinal sensitivity in the inferior quadrants of the visual field compared to non-athletes. The results suggest that practice helps athletes develop specific visual skills that allow them to perform motor maneuvers under time pressure conditions. This study can help direct the training of soccer players to help develop and enhance visual perception for professional soccer championship.

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