Available online at www.sciencedirect.com

ScienceDirect

Journal of Sport and Health Science 9 (2020) 587−594

www.jshs.org.cn

Original article

Visual function, performance, and processing of basketball players *vs.* sedentary individuals

Jesús Vera [a,*], Raimundo Jiménez [a], David Cárdenas [b,c], Beatriz Redondo [a], José Antonio García [a]

[a] *Department of Optics, Faculty of Science, University of Granada, Granada 18071, Spain*
[b] *Department of Physical Education and Sport, Faculty of Sport Science, University of Granada, Granada 18071, Spain*
[c] *Sport and Health University Mixed Institute, University of Granada, Granada 18071, Spain*

Received 16 November 2016; revised 1 February 2017; accepted 6 March 2017
Available online 4 May 2017

Abstract

Background: Athletes tend to have better visuo-motor performance than do sedentary individuals. However, several basic visual-function and perceptual parameters remain unexplored to date. In this study, we investigated whether differences exist in visual function, performance, and processing between basketball players and individuals without a sport-involvement background.

Methods: A total of 33 healthy men with no visual impairment or pathology were divided into 2 groups, depending on the involvement in sport (semi-professional basketball players and sedentary individuals). We tested their baseline heart-rate variability in the resting position apart from subjective questionnaires to determine their physical fitness level, and we checked their visual function, performance, and processing through an extended battery of optometric tests.

Results: The 2 groups differed in resting heart-rate variability parameters ($p < 0.001$), confirming their dissimilarities in regular time practising sports per week. The basketball players showed a closer breakpoint and recovery nearpoint of convergence, a higher fusional-vergence rate, better discriminability halos, and better eye−hand coordination (all p values < 0.05).

Conclusion: These results show evidence that athletes, basketball players in this case, exhibit better performance in several visual abilities in comparison to a group of individuals without sporting backgrounds, suggesting an improvement due to the systematic involvement of those skills during basketball practice.

Keywords: Exercise; Fitness level; Health; Heart rate variability; Visual skills; Team sport

1. Introduction

Athletes need to gather a great amount of information, mainly visual, swiftly from the environment in order to execute appropriate motor tasks.[1] There is evidence that athletes develop peculiar mechanisms of occipital neural synchronization during visuo-spatial demands, showing better visuo-motor performance compared to non-athletes.[2] Previous studies tend to indicate that athletes present better visual skills than do sedentary individuals, but this issue is far from being settled.[3] Several studies have questioned whether visual skills in athletes are innate or whether they are improved with systematic sport practice.[4] In this context, it has been established that constant practice and sport vision-training programs help to improve certain visual abilities, while the innate contributions seem to be insignificant.[5,6]

Previous investigation suggests that particular sets of visual skills are sport-dependent because each discipline has differing visual needs and demands.[7] The visual information during basketball, as a dynamic sport, comes from the position of the ball and player. Thus, basic visual function based on good optical quality, oculomotor coordination, binocular and accommodative function, or stereopsis, are crucial to success in ball games and particularly in basketball.[8] In addition, a player's performance depends on cognitive capabilities and the visuo-motor reaction times.[9]

Nevertheless, it has not been clarified whether athletes' superiority is due to basic visual function or perceptual and cognitive skills.[10] An increasing body of knowledge supports a multidimensional approach, considering visual, perceptual, and cognitive factors to characterise expertise.[11] Although some studies have concluded that athletes possess better visual function than

---

Peer review under responsibility of Shanghai University of Sport.

* Corresponding author.
E-mail address: jesusvv@correo.ugr.es (J. Vera).

https://doi.org/10.1016/j.jshs.2017.05.001

Cite this article: Vera J, Jiménez R, Cárdenas D, Redondo B, García JA. Visual function, performance, and processing of basketball players *vs.* sedentary individuals. *J Sport Health Sci* 2020;9:587−94.

do sedentary individuals,[12] few investigations have used an extended optometric battery of tests in a specific sport discipline and, thus, no solid conclusions have been drawn to date. For example, differences between professional volleyball players and a control group have been reported for saccadic eye movements and facility of ocular accommodation,[13] as well as better near stereoacuity in young baseball/softball players in comparison to non-ball players.[14] By contrast, Paulus et al.[15] found that stereopsis in soccer players was similar to that of individuals without soccer backgrounds. On the other hand, visual information processing also plays a fundamental role in sport performance, permitting a precise decision-making process in a certain amount of time.[16] Several studies have shown that athletes have better peripheral awareness and ability to track a moving target, and they have a different strategy in the treatment of visual information, among other advantages, than do non-athletes or less experienced players.[6,17,18] Specifically, in a recent study, Mangine et al.[16] found a relationship between faster visual-tracking speed and better basketball-specific performance in players in the National Basketball Association.

Considering the previous literature and the ongoing debate concerning the differences in visual function and perceptual abilities between athletes and the sedentary population, in the present study we investigated the basic visual function and perceptual visual skills in a specific sport discipline, basketball in our case, in order to provide more knowledge in this regard. Therefore, we tested several parameters related to the basic visual function, such as accommodative response, near point of convergence, near and far fusional vergences, and near and far stereoacuity. Regarding perceptual abilities, we also assessed visual performance by visual-discrimination capacity and visual-information processing by visual-reaction time and eye−hand coordination.

Additionally, exercise practice has been demonstrated to improve the autonomic balance through an increase in parasympathetic and a decrease in sympathetic control of heart rate (HR).[19,20] Heart rate variability (HRV) analysis with the time and frequency domains permits assessment of the state of the autonomic nervous system, which indirectly reflects fitness level.[21] To check the differences in physical exercise involvement between athletes and individuals without a sport background, we measured HRV at rest and compiled subjective report data. We hypothesised that inherent visual involvement during systematic basketball practice can improve both the basic visual function and the main perceptual visual parameters involved. The answer to our research question can have theoretical and practical consequences for basketball performance and training protocols.

2. Methods

2.1. Participants and ethical approval

The study included a total of 33 male university students, of whom 18 belonged to different basketball teams in a regional league, and 15 had no history of sporting activity (age: 23.28 ± 2.37 years and 22.27 ± 2.09 years, mean± SD, respectively) (Table 1). Participants were asked about the type of sport activities that they were engaged in apart from basketball and the amount of time dedicated to each sport discipline. From the basketball group, 15/18 reported that they practiced strength training in addition to the basketball sessions, and the other 3 were engaged only in basketball. All basketball players had been playing at competitive levels for at least 7 years (10.24 ± 2.27). Regarding the sedentary participants, 8 individuals reported occasionally practicing team sports, and the rest of them (7 participants) were not involved in any physical activity. This study was conducted according to the Code of Ethics of the World Medical Association (Declaration of Helsinki), and permission was provided by the Institutional Review Board of University of Granada. All participants gave written informed consent prior to the study.

Admission criteria included: (1) being healthy; (2) practising 6 h or more of moderate exercise per week for the athlete group and 1 h or less of exercise per week for the non-athlete group; (3) not presenting any ocular pathology; (4) not taking any medication; (5) presenting static monocular (in both eyes) and binocular visual acuity ≤ 0 logMAR ($\geq 20/20$); (6) having a corrected refractive error $\leq$ 3.5 diopters for myopia and hyperopia and $\leq$ 1.5 diopters of astigmatism and being contact lens wearers; and (7) scoring less than 25 on the Conlon Survey,[22] which assesses visual discomfort, and less than 21 on the Convergence Insufficiency Symptom Survey[23] (Table 1). All participants were instructed to avoid alcohol consumption and vigorous exercise 24 h before the experiment session, to sleep for at least 7 h, not to consume caffeine beverages or other stimulants in the 3 h prior to testing, and to follow their regular diets but not to eat 2 h prior to testing.

Table 1
Anthropometrical and visual characteristics and visual symptomatology of the 33 participants included in this study by groups (mean ± SD, range).

Sample characteristics	Basketball players ($n = 18$)	Sedentary subjects ($n = 15$)
Age (year)	23.28 ± 2.37 (20 to 28)	22.27 ± 2.09 (20 to 27)
Height (cm)	177.17 ± 7.26 (167 to191)	181.8 ± 4.97 (173 to 190)
Weight (kg)	71.85 ± 7.48 (62 to 88)	75.87 ± 10.35 (60 to 95)
Visual acuity (logMAR)	−0.14 ± 0.08 (−0.2 to 0)	−0.15 ± 0.06 (−0.2 to 0)
Spherical refractive error (D)	−0.25 ± 0.80 (−3.375 to 0)	−1.01 ± 1.43 (−3.5 to 0)
Astigmatism (D)	0.03 ± 0.12 (0 to 0.5)	0.32 ± 0.43 (0 to1.13)
Subjective measures		
Conlon survey	5.77 ± 4.25 (0 to 17)	7.47 ± 5.74 (0 to 19)
CISS	6.11 ± 4.19 (0 to 16)	8.47 ± 5.82 (0 to 19)

Abbreviations: CISS = convergence insufficiency symptoms survey; D = diopters; LogMAR = logarithm of the minimum angle of resolution.

2.2. *Test procedures and apparatus*

2.2.1. *HRV measure and analysis*

To ensure differences in physical involvement, we measured HRV.[24] A number of studies have concluded that endurance training enhances vagal tone in athletes, which may contribute in part to lower the resting HR.[19] Thus, before the visual examination, the participant was asked to lie in a supine position in a quiet room for 6 min. The HR was monitored by using a Polar RS800CX wrist device (Polar Electro Oy., Kempele, Finland) set to measure both the HR and HRV. The time series of HRV was taken from the electrocardiogram, identifying the occurrence of each R wave (belonging to the QRS complex) and calculating the time lapse between 2 consecutive R waves.[21] Subsequently, the data were transferred to the Polar ProTrainer Software (Polar Electro), and each downloaded R-R interval (inter-beat R wave to R wave) file was then further analysed using the Kubios HRV Analysis Software 2.0 (The Biomedical Signal and Medical Imaging Analysis Group, Department of Applied Physics, University of Kuopia, Finland).[25] R-R intervals that differed more than 25% from the previous and subsequent R-R intervals were excluded. The removed R-R intervals were replaced by conventional spline interpolation so that the length of the data did not change. In this study, the parameters used to analyse HRV within the time domain were the mean R-R interval and the root-mean-square difference of successive normal R-R intervals (rMSSD), and within the frequency domain were the low-frequency and high-frequency components in normalized units, which are established to be between 0.04 Hz and 0.15 Hz and 0.15 Hz and 0.4 Hz, respectively.[19]

2.2.2. *Ocular and visual examination*

Ocular parameters related to ocular refraction, accommodative and binocular function, visual performance, and visual information processing were examined. All tests were conducted under photopic illuminance conditions (152.4 ± 2.45 lux), with the exception of visual discrimination in scotopic illuminance conditions ($\sim$ 0 lux), which were quantified in the corneal plane with an illuminance meter T-10 (Konica Minolta, Tokyo, Japan).

2.2.3. *Ocular refraction*

Monocular and binocular visual acuity was determined by using a computerized monitor with the logarithmic letters chart test employing the Bailey-Lovie design (POLA VistaVision, DMD Med Tech, Torino, Italy) at a distance of 5 m.

Ocular refraction consisted of an objective refraction with non-cyclopegic retinoscopy while the participant maintained a fixed gaze on a distant non-accommodative target and, finally, each participant underwent a full monocular and binocular subjective refraction, using an endpoint criterion of maximum plus consistent with best vision.

2.2.4. *Accommodation, binocular, and oculomotor parameters*

All tests were conducted with the best correction, following the recommendations given by Scheiman and Wick.[26]

The accommodative response, measured by the monocular estimate method of retinoscopy, was carried out by very briefly interposing, in front of 1 eye at a time, convergent or divergent lenses until neutralizing the reflex found in the horizontal meridian, while the participant read a test close-up with 0.18 logMAR (20/30) letters.

The near point of convergence was evaluated by the push-up technique using an accommodative target. A 0.18 logMAR (20/30) single letter on the fixation stick was used as the target. The target was moved closer until the participant experienced constant diplopia on the stick (breakpoint). Then we asked the patient to move it away from the eye until single vision was restored (recovery point).

Near and distance negative and positive vergence amplitudes were measured. The negative fusional vergence was measured first to avoid affecting the vergence-recovery value because of excessive stimulation of convergence. A gradually increasing prism bar was introduced in the dominant eye while the patient fixed the gaze on a column of the Snellen optotype, corresponding to the highest visual acuity at 40 cm and 6 m fixation, respectively. When the prism caused the patient to experience double vision, the amount of prism (breakpoint) was recorded. The prism power was then reduced until the double images could be fused again (recovery point).

Static far stereo acuity was tested using the Stereo D6/D8 (POLA VistaVision) at 5 m away using a polarizing viewer. This test presents a range from a maximum of 300 s of arc to a minimum of 10 s of arc, and only 1 circle from 5 possible choices had crossed disparity. The participant was asked to identify which circle seemed to be at a different distance with respect to the other 2 (at near) or 4 (at distance). Static near stereo acuity was measured using the Randot Stereotest Circles (Stereo Optical, Chicago, IL, USA) at a distance of 40 cm. Within each of 10 targets, there were 3 circles. This test presents a range from a maximum of 400 s of arc to a minimum of 20 s of arc. The level of stereoacuity was recorded as the last series of targets answered correctly.

To test facility of accommodation, the Hart chart was read under binocular conditions. This procedure presents blur and vergence-related visual feedback and function in an interactive manner.[27] Participants were instructed to read alternatively 1 letter from the distance Hart chart (5 m) in primary position and then shift their focus to the near Hart chart (40 cm) placed 30° inferiorly, and so forth, across the lines of letters as rapidly as possible. The number of cycles completed in 60 s was determined as well as the number of errors made.

2.2.5. *Visual performance*

We evaluated the visual-discrimination capacity, quantifying the visual disturbances perceived by the participant by using a visual test conducted by the software Halo, version 1.0 (freeware software, University of Granada, Granada, Spain).[28] The participant's task consisted of detecting luminous peripheral stimuli around a central high-luminance stimulus over a dark background. All of the stimuli were achromatic. The distance from the observer to the test monitor (1280 × 1024 LCD screen) was 2.5 m, and the test was performed binocularly. The size of the stimulus was 39 pixels for the radius of the central stimulus and 1 pixel for the peripheral stimulus, subtending 0.61 degrees and 0.02 degrees, respectively, from the observer's position. The monitor showed 72 peripheral stimuli around the central one, distributed along 18 semi-axes. Each of the 72 stimuli was presented twice. After a 3-min adaption period to the darkness of the monitor background, there was 1-min adaptation to the main stimulus, and then the participant was randomly presented with peripheral stimuli around the central stimulus. On detecting peripheral spots, the participant pressed a button on the mouse to store this information for subsequent treatment and calculation of the visual disturbance index (VDI) after the test was concluded. The VDI takes values from 0 to 1. A greater value indicates a greater contribution of visual disturbances, such as glare or visual halos around the luminous stimuli and, therefore, poorer discrimination capacity.

2.2.6. *Visual-information processing*

The Wayne Saccadic fixator (Wayne Engineering, Skokie, IL, USA) was used for evaluating visual reaction time. This apparatus consists of a 29-inch square panel containing 33 red-light switches. A computer chip generates a variety of patterns of light to which an individual responds by pushing the illuminated switch to extinguish the light. A great variety of display patterns, speeds, and situations can be programmed. The Sports Vision Release/Locate Reaction Time program, used to test visual reaction time, was performed 3 times after familiarization. The test instructions consisted of pressing the start/reset button, holding the button down until a signal was heard (liberalization time), releasing the button, and pressing the illuminated light/button on the saccadic fixator (localization time). Just one light was used, and it appeared in a random position each time. Two scores were given to each trial for the time of liberalization and location (milliseconds).[29,30]

To test eye−hand coordination, we used a standardized test developed by Dr. Jack Gardner, which employs the Wayne Saccadic Fixator; it jointly takes into account the proaction (time period in which each light stays lit until the button is pressed) and reaction times (preset amount of time in which each light stays lit before automatically switching to another light, regardless of whether the button is pressed) for accurate and repeatable rapid testing. The lights start moving automatically at the preset speed (60 lights/min). For each correct response, the speed increases. At the end of the preset time (30 s), the display shows the number of correct responses, the average speed, and the final speed in lights/min. The score is the product of the number of lights scored and the final speed of presentation of the lights.[29]

Three measurements were taken in the monocular estimate method: near point of convergence (break and recovery points) and visual reaction time, and the mean value was used. When both eyes had to be measured independently, the order of the first eye was randomized, and if no statistical significance was found between eyes, the mean values were analysed.[31]

2.3. *Statistical analysis*

All variables tested were subjected to the Shapiro-Wilks test, showing a normal Gaussian distribution. Thus, to analyse the differences in visual function between basketball players and sedentary participants, a separate *t* test was performed for independent samples, and each variable was tested. We used the Bonferroni correction for multiple comparison. A value of 0.05 was adopted to determine significance.

3. Results

3.1. *Sample manipulation check*

The *t* test for independent samples showed significant differences between basketball players and sedentary participants in the HR (beats/min) ($t_{31} = -7.07$, $p < 0.001$), R-R interval (ms) ($t_{31} = 7.09$, $p < 0.001$), rMMSD (ms) ($t_{31} = 5.14$, $p < 0.001$), low-frequency (nu) ($t_{31} = -5.28$, $p < 0.001$), and high-frequency (nu) ($t_{31} = 5.27$, $p < 0.001$) (Table 2*)*. Also, a *t* test for independent samples was performed for hours per week of exercise ($t_{31} = 21.179$, $p < 0.001$) and for hours per week of basketball practice ($t_{31} = 39.57$, $p < 0.001$) reported by participants. Hence, the 2 samples showed different fitness levels.

3.2. *Visual parameters*

Table 3 presents mean values ± SD and significance for all parameters tested in this study.

The analysis for fusional vergence showed that athletes had higher far positive fusional vergence range ($t_{31} = 2.69$, $p = 0.011$ for the breakpoint, and $t_{31} = 3.02$, $p = 0.005$ for the

Table 2
HRV at rest and hours of exercise practice of the 33 participants included in this study by groups (mean ± SD).

HRV parameters at rest	Basketball players ($n = 18$)	Sedentary subjects ($n = 15$)	*p*
HR (beats/min)	62.26 ± 7.32	82.86 ± 9.39	< 0.001
RRi (ms)	992.06 ± 116.73	739.92 ± 84.31	< 0.001
rMSSD (ms)	694.06 ± 238.28	354.97 ± 149.2	< 0.001
LF (nu)	53.27 ± 14.67	78.09 ± 11.81	< 0.001
HF (nu)	46.65 ± 14.65	21.90 ± 11.82	< 0.001
Exercise practice involvement (h)			
Exercise per week	10.22 ± 1.73	0.27 ± 0.59	< 0.001
Basketball practice per week	9.39 ± 0.92	0	< 0.001

Abbreviations: HF = high frequency; HR = heart rate; HRV = heart-rate variability; LF = low frequency; nu = normalized units; rMSSD = root-mean-square difference of successive normal R-R intervals; RRi = R-R interval.

Table 3
Ocular parameters evaluated according to the measurement method and group analysed. Means ± SD were calculated from the mean values of each participant ($n = 33$, mean ± SD).

Ocular measurements	Basketball players	Sedentary subjects	p
Binocular and accommodative function			
Accommodative response (D)[a]	0.50 ± 0.25	0.38 ± 0.24	0.155
Accommodative facility (cpm)[b]			
Cpm	25.67 ± 3.46	27.60 ± 3.36	0.116
Errors	2.44 ± 2.28	1.27 ± 1.58	0.101
Near point of convergence (cm)[c]			
Break	4.66 ± 1.25	6.24 ± 1.66	**0.004**
Recovery	7.01 ± 2.68	9.53 ± 2.85	**0.014**
Far negative fusional vergence (Δ)[d]			
Break	10.06 ± 4.47	9.60 ± 3.87	0.759
Recovery	7.18 ± 2.89	7.47 ± 3.89	0.812
Far positive fusional vergence (Δ)[d]			
Break	26.41 ± 8.03	18.27 ± 9.33	**0.011**
Recovery	20.06 ± 7.21	12.33 ± 7.44	**0.005**
Near negative fusional vergence (Δ)[d]			
Break	13.63 ±3.37	13.07 ± 4.06	0.666
Recovery	10.78 ± 3.40	10.67 ± 4.05	0.932
Near positive fusional vergence (Δ)[d]			
Break	27.72 ± 8.08	21.20 ± 11.04	0.059
Recovery	23.43 ± 7.92	16.93 ± 11.24	0.061
Near static stereo acuity (s of arc)[e]	38.33 ± 20.72	86.33 ± 128.71	0.128
Far static stereo acuity (s of arc)[f]	84.44 ± 48.17	79.33 ± 72.85	0.811
Visual performance			
VDI[g]	0.41 ± 0.24	0.68 ± 0.23	**0.003**
Visual-motor processing[h]			
Eye–hand coordination (lights × final speed)	2227.61 ± 507.45	1688.00 ± 774.05	**0.022**
Visual-reaction time (ms)			
Liber	291.89 ± 58.67	286.40 ± 54.49	0.784
Location	507.39 ± 94.51	463.60 ± 164.73	0.346

[a] Measured by MEM.
[b] Measured by Hart chart.
[c] Measured by Push-up.
[d] Measured by Prism bar (steps).
[e] Measured by Randot Stereotest Circles.
[f] Measured by Stereo D6/D8.
[g] Measured by Software Halo Version 1.0.
[h] Measured by Wayne Saccadic Fixator.
Abbreviations: Δ = prismatic diopter; cpm = cycles per minute; MEM = monocular estimated method; VDI = visual disturbance index.

recovery value). Regarding near positive fusional vergence, basketball players reached marginally significant higher fusional vergence values for the breakpoint and recovery ($t_{31} = 1.957$, $p = 0.059$, and $t_{31} = 1.941$, $p = 0.061$, respectively). For the near point of convergence, closer breakpoints and recovery values were found for athletes ($t_{31} = -3.133$, $p = 0.004$ and $t_{31} = -2.615$, $p = 0.014$, respectively). Finally, the accommodative response, facility of accommodation, and static near and far stereo acuity yielded no significant differences ($p > 0.05$) between groups (Table 3).

Participants without basketball backgrounds demonstrated significantly higher VDI than did the basketball players ($t_{31} = -3.282$, $p = 0.003$) (Table 3) (Fig. 1, illustrating 2 participants in each experiment group).

Basketball players showed better scores for eye–hand coordination ($t_{31} = 2.405$, $p = 0.022$). On the other hand, visual-reaction time revealed no differences for liberation and location times ($p = 0.784$ and $p = 0.346$, respectively) (Table 3).

4. Discussion

This investigation incorporates noteworthy findings in several categories: basketball players show a closer near point of convergence for breakpoint and recovery, a larger positive fusional vergence range, a better VD1 index (e.g., lower scores), and higher scores in eye–hand coordination than do sedentary participants.

4.1. Accommodative and binocular function

In basketball, near/far visual changes are continual for ball interceptions, control, passing, and throwing the ball, as well as analysing the positioning of teammates and opponents, among others.[16] These types of actions promote a constant implication of the vergence/accommodative system, which could produce an effect comparable to visual therapy exercises. Exercises based on constant near/far changes in binocular viewing conditions are normally applied in optometry practice with the aim of normalising the accommodative and

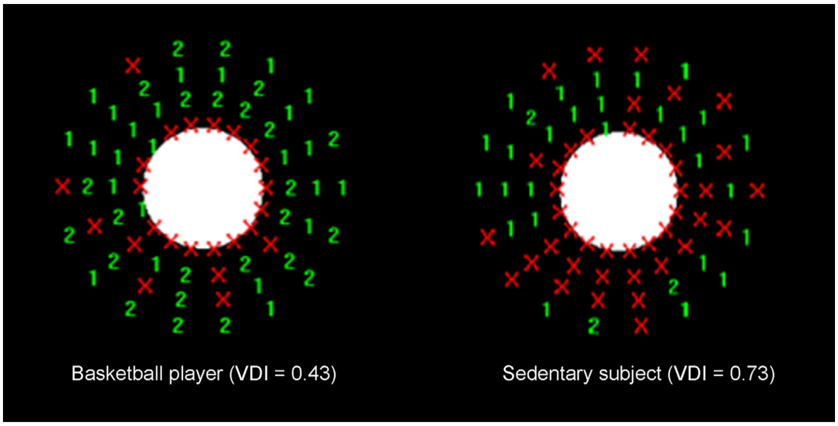

Fig. 1. Visual discrimination index (VDI) diagrams of 2 participants belonging to each experimental group (basketball $n = 11$; sedentary $n = 4$). Data in green represent correct responses: Numbers 1 and 2 indicate whether the stimulus was identified just once or both times, respectively. Red crosses indicate that no stimulus was identified in that position.

vergence system as well as their mutual interactions.[32] Notably, we found that basketball players present a closer near point of convergence and larger far positive fusional vergences in comparison with the sedentary group. Similar results were reported by Christenson and Winkelstein[33] and by Coffey and Reichow,[34] who found a closer near point of convergence and greater distance vergences ranges in athletes, respectively. On the contrary, no significant differences were found in the negative fusional vergences between groups in the current study. Similarly, Daum[35] demonstrated that visual training in young adults with normal binocularity has a significant and prolonged effect on positive vergences, while fusional negative vergences resisted change. These substantial differences between the convergence and divergence systems seem to be explained by their being controlled by different neural centres. It is also well known that visual therapy gives the best results in the treatment of convergence insufficiency, acting on the reduced positive fusional vergences and the receded near point of convergence.[36]

No statistical differences were found for near static stereopsis, but a tendency to present different values between groups was appreciable (38.33 ± 20.72 for the basketball group *vs.* 86.33 ± 128.71 for the sedentary group). Along this line, Boden et al.[14] found significant differences between baseball/softball players and non-ball players (25.5 ± 11.9 and 56.2 ± 60.7, respectively). Similarly, we found no differences for far static stereoacuity, and these results agree with those of Paulus et al.,[15] who made comparisons for far static and dynamic stereopsis in professional and amateur soccer players *vs.* individuals without soccer backgrounds. The effect of specific eye exercises on stereoacuity seemed to be modest and has limited use in practical terms.[37] Therefore, we can expect that systematic basketball practice does not involve substantial stereopsis improvements. Also, as indicated by Paulus et al.,[15] stereopsis tests are not sensitive enough to reveal differences between groups, and further developments in test methodology of stereopsis are needed.

The accommodative system is controlled by the autonomic nervous system, and that system is more stable and efficient in athletes.[13] Therefore, we might expect a better accommodative function in basketball players, but we detected no significant differences in the accommodative responses between groups. We propose 2 possible explanations: firstly, the possible accommodation variations may be relatively smaller than monocular estimate method sensitivity (0.25 D), and more sensitive methods to test accommodative response would be necessary (e.g., open-field autorefractor or wavefront sensors). Secondly, and perhaps most influential, the ball and players are moving mainly at medium to long distances, which do not require great accommodative effort. Therefore, accommodation enhancements, which require high accommodative stimulation in visual training,[38] are unlikely to be achieved only with regular basketball practice.

For its part, facility of accommodation in binocular conditions revealed no differences between groups. Little comparable work has been conducted, and only Jafarzadehpur et al.[13] found significant differences when they compared professional and intermediate female volleyball players with beginners and non-players, but those differences disappeared when professionals were compared to intermediates. However, the method of measuring used in their work is not clear. Other authors, using a methodology similar to that used in the present work, showed slightly better accommodative facility for a wide group of interceptive sports athletes than for non-athletes.[39] That study involved not only basketball players but also a great variety of sport modalities (e.g., tennis, table tennis, baseball, volleyball, badminton), and the visual requirements for each discipline are substantially different.

4.2. *Visual performance*

No study available has investigated visual performance in sports using the VDI. The present study reports better visual discrimination in athletes. It has importance because the perception of halos requires a longer time to recover after exposure to a high-luminance stimulus (e.g., glare).[40] The glare phenomenon has great importance in basketball, and players are constantly exposed to glare due to illumination conditions in basketball courts.[41] The differences found between basketball players and sedentary individuals could be explained from the perspective that abilities involved during the game are inherently developed while playing the sport (e.g., higher tolerance),[6] as occurs with the better selective attention demonstrated in international basketball players.[42]

4.3. *Visual-information processing*

Our results confirm that basketball players show better eye-hand coordination than do individuals without basketball background. This study agrees with Houmourtzoglou et al.,[42] who found a similar result in members of a Greek national team, arguing different perceptual strategies from experts to novices in relevant and irrelevant cues. In relation to visual reaction times, previous studies have indicated that players in various disciplines (e.g., water polo or soccer) had faster visual reaction times compared with novices or non-athletes, but no differences were found for basketball players, as in this study.[43] It may demonstrate that the nature of each sport strongly influences the development of visual skills with constant practice. Along the same line, other authors have stated that athletes have a speed of response similar to that of non-athletes but differ in the ability to detect pertinent cues associated with the higher level of expertise in sport.[44]

4.4. *A plausible explanation*

Previous works have supported the contention that differences between an athlete and a sedentary participant arise from visual-information processing and interpretation rather than from basic visual skills.[2] This study supports the hypothesis that athletes could present a combination of better basic visual function as well as perceptual and cognitive factors than do non-athletes, as explained by several authors.[6,10,13,45] However, this study does not elucidate whether there is an innate visual superiority in athletes or whether those superior skills are achieved due to the constant sport practice. In addition, the differing visual demands required in each sport discipline could influence the development of visual, perceptual, and cognitive skills. The vast majority of studies have reported that better visual skills would play a positive role in sport performance. This advantage in visuo-oculomotor abilities can lead to faster and better interceptive skills, motor responses, and decision making.[39,46] For example, a recent study indicates that visual tracking speed is related to a greater number of assists and steals and lower turnovers in National Basketball Association players.[16] Moreover, considering that our athletes never received specific visual training, it is implied that basketball training in itself might be responsible for the differences in some visual capacities between basketball players and non-players, as explained by Alves et al.[18] for professional soccer players.

4.5. *Implications for future research*

Because of the great number of sport disciplines, further studies should be performed to analyse the differences presented to the visual system. We would like to encourage researchers to investigate whether visual training could be transferred to sport performance in the field environment. Some work is currently being performed in this area,[5] but more data are needed. It would be useful to explore the possible visual-function improvements with systematic sport practice in persons who have impaired visual function (e.g., convergence insufficiency, vergence fusional dysfunction, *etc.*), as has been demonstrated in various health conditions.[47]

5. Conclusions

This study presents evidence of the differences between basketball players and sedentary individuals with respect to some skills in their visual function, performance, and processing. Both groups proved to have different sport backgrounds, as reflected by the HRV parameters and as indicated in the demographic questionnaire. In comparison to the control group, basketball players clearly present superiority in near point of convergence, positive fusional vergences, halo discriminability, and eye−hand coordination. Our results suggest that systematic basketball practice might be responsible for the development of certain visual abilities.

Acknowledgments

The authors thank Ernesto Suarez and David Nesbitt for translating the text into English. We also acknowledge all the participants who selflessly participated in this study. The study was funded in part by a Spanish Ministry of Economy and Competitiveness grant #DEP2013-48211-R.

Authors' contributions

JV conceived the study, participated in data collection, performed the statistical analysis, and drafted the manuscript; RJ conceived the study, coordinated and drafted the manuscript; DC coordinated and helped to draft the manuscript; BR participated in data collection and drafted the manuscript; JAG coordinated and drafted the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing Interest

The authors declare that they have no competing interests.

References

1. Babu RJ, Lillakas L, Irving EL. Dynamics of saccadic adaptation: differences between athletes and nonathletes. *Optom Vis Sci* 2005;**82**:1060–5.
2. Del Percio C, Brancucci A, Vecchio F, Marzano N, Pirritano M, Meccariello E, et al. Visual event-related potentials in elite and amateur athletes. *Brain Res Bull* 2007;**74**:104–12.
3. Barrett BT. A critical evaluation of the evidence supporting the practice of behavioural vision therapy. *Ophthalmic Physiol Opt* 2009;**29**:4–25.
4. Ludeke A, Ferreira JT. The difference in visual skills between professional versus non-professional rugby players. *South African Optom* 2003;**62**:150–8.

5. Schwab S, Memmert D. The impact of a sports vision training program in youth field hockey players. *J Sport Sci Med* 2012;**11**:624–31.
6. Quevedo-Junyent L, Aznar-Casanova JA, Merindano-Encina D, Cardona G, Solé-Fortó J. Comparison of dynamic visual acuity between water polo players and sedentary students. *Res Q Exerc Sport* 2011;**82**:37–41.
7. Laby DM, Kirschen DG, Pantall P. The visual function of olympic-level athletes—an initial report. *Eye Contact Lens* 2011;**37**:116–22.
8. Sillero M, Refoyo I, Lorenzo A, Sampedro J. Perceptual visual skills in young highly skilled basketball players. *Percept Mot Skills* 2007;**104**:547–61.
9. Kioumourtzoglou E, Kourtesses T, Michalopoulou M, Derri V. Differences in several perceptual abilities between experts and novices in basketball, volleyball and water-polo. *Percept Mot Skills* 1998;**86**:899–912.
10. Ryu D, Abernethy B, Mann DL, Poolton JM, Gorman AD. The role of central and peripheral vision in expert decision making. *Perception* 2013;**42**:591–607.
11. Ward P, Williams AM. Perceptual and cognitive skill development in soccer: the multidimensional nature of expert performance. *J Sport Exerc Psychol* 2003;**25**:93–111.
12. Ciuffreda KJ, Wang B. Vision training and sports. In: Hung GK, Pallis JM, editors. *Biomedical Engineering Principles in Sports*. Vol.1. New York, NY: Springer; 2004.p.407–33.
13. Jafarzadehpur E, Aazami N, Bolouri B. Comparison of saccadic eye movements and facility of ocular accommodation in female volleyball players and non-players. *Scand J Med Sci Sports* 2007;**17**:186–90.
14. 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* 2009;**80**:121–5.
15. Paulus J, Tong J, Hornegger J, Schmidt M, Eskofier B, Michelson G. Extended stereopsis evaluation of professional and amateur soccer players and subjects without soccer background. *Front Psychol* 2014;**5**:1–7.
16. Mangine GT, Hoffman JR, Wells AJ, Gonzalez AM, Rogowski JP, Townsend JR, et al. Visual tracking speed is related to basketball basketball-specific measures of performance in NBA players. *J strength Cond Res* 2014;**28**:406–14.
17. Uchida Y, Kudoh D, Murakami A, Honda M, Kitazawa S. Origins of superior dynamic visual acuity in baseball players: superior eye movements or superior image processing. *PLoS One* 2012;**7**:e31530. doi:10.1371/journal.pone.0031530.
18. Alves M, Spaniol F, Erichsen O. Visual skills of elite Brazilian soccer players. *Eur J Sport Sci* 2014;**4**:1–9.
19. Aubert AE, Seps B, Beckers F. Heart rate variability in athletes. *Sport Med* 2003;**33**:889–919.
20. Carter JB, Banister EW, Blaber AP. Effect of endurance exercise on autonomic control of heart rate. *Sport Med* 2003;**33**:33–46.
21. Acharya UR, Joseph KP, Kannathal N, Lim CM, Suri JS. Heart rate variability: a review. *Med Biol Eng Comput* 2006;**44**:1031–51.
22. Conlon EG, Lovegrove WJ, Chekaluk E, Pattison PE. Measuring visual discomfort. *Vis Cogn* 1999;**6**:637–63.
23. Horwood AM, Toor S, Riddell PM. Screening for convergence insufficiency using the CISS is not indicated in young adults. *Br J Ophthalmol* 2014;**98**:679–83.
24. Pumprla J, Howorka K, Groves D, Chester M, Nolan J. Functional assessment of heart rate variability: physiological basis and practical applications. *Int J Cardiol* 2002;**84**:1–14.
25. Tarvainen MP, Niskanen JP, Lipponen JA, Ranta-Aho PO, Karjalainen PA. Kubios HRV: heart rate variability analysis software. *Comput Methods Programs Biomed* 2014;**113**:210–20.
26. Scheiman M, Wick B. *Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders*. Philadelphia, PA: Lippincott Williams & Wilkins; 2008.
27. Vasudevan B, Ciuffreda KJ, Ludlam DP. Accommodative training to reduce nearwork-induced transient myopia. *Optom Vis Sci* 2009;**86**:1287–94.
28. Castro JJ, Pozo AM, Rubiño M, Anera RG, Jiménez Del Barco L. Retinal-image quality and night-vision performance after alcohol consumption. *J Ophthalmol* 2014;**2014**:704823. doi:10.1155/2014/704823.
29. Vogel G, Hale R. Initial norms using the Wayne Saccadic Fixator: eye-hand coordination and visual reaction times. *J Behav Optom* 1990;**1**:206–11.
30. Abernethy B, Wood JM. Do generalized visual training programmes for sport really work? An experimental investigation. *J Sports Sci* 2001;**19**:203–22.
31. Armstrong R. Statistical guidelines for the analysis of data obtained from one or both eyes. *Ophthalmic Physiol Opt* 2013;**33**:7–14.
32. Ciuffreda KJ. The scientific basis for and efficacy of optometric vision therapy in nonstrabismic accommodative and vergence disorders. *Optometry* 2002;**73**:735–62.
33. Christenson GN, Winkelstein AM. Visual skills of athletes versus nonathletes: development of a sports vision testing battery. *J Am Optom Assoc* 1988;**59**:666–75.
34. Coffey B, Reichow AW. Athletes *vs*. non athletes: 6m vergence ranges, accommodative vergence facility and 6m speed of stereopsis. *Optom Vis Sci* 1990;**67**:81.
35. Daum K. The course and effect of visual training on the vergence system. *Am J Optom Physiol Opt* 1982;**59**:223–7.
36. Scheiman M, Mitchell GL, Cotter S, Kulp MT, Cooper J, Rouse M, et al. A randomized clinical trial of vision therapy/orthoptics versus pencil pushups for the treatment of convergence insuffciency in young adults. *Optom Vis Sci* 2005;**82**:583–95.
37. Rawstron J, Burley C, Elder M. A systematic review of the applicability and efficacy of eye exercises. *J Pediatr Ophthalmol Strabismus* 2005;**42**:82–8.
38. Liu J, Lee M, Jang J, Ciuffreda KJ, Wong JH, Grisham D, et al. Objective assessment of accommodation orthoptics. I. Dynamic insufficiency. *Am J Optom Physiol Opt* 1979;**56**:285–94.
39. Gao Y, Chen L, Yang SN, Wang H, Yao J, Dai Q, et al. Contributions of visuo-oculomotor abilities to interceptive skills in sports. *Optom Vis Sci* 2015;**92**:679–89.
40. Dick HB, Krummenauer F, Schwenn O, Krist R, Pfeiffer N. Objective and subjective evaluation of photic phenomena after monofocal and multifocal intraocular lens implantation. *Ophthalmology* 1999;**106**:1878–86.
41. Sun WS, Tien CL, Tsuei CH, Pan JW. Simulation and comparison of the illuminance, uniformity, and efficiency of different forms of lighting used in basketball court illumination. *Appl Opt* 2014;**53**:186–94.
42. Kioumourtzoglou E, Kourtesses T, Michalopoulou M, Derri V. Differences in several perceptual abilities between experts and novices in basketball, volleyball and water-polo. *Percept Mot Skills* 1998;**86**:899–912.
43. Soichi A, Oda S. Central and peripheral visual reaction time of soccer players and nonathletes. *Percept Mot Skills* 2001;**92**:786–94.
44. Ripoll H, Kerlirzin Y, Stein JF, Reine B. Analysis of information processing, decision making, and visual strategies in complex problem-solving sport situations. *Hum Mov Sci* 1995;**14**:325–49.
45. Ward P, Williams AM. Perceptual and cognitive skill development in soccer: the multidimensional nature of expert performance. *J Sport Exerc Psychol* 2003;**25**:93–111.
46. Erickson GB. *Sports vision: vision care for the enhancement of sports performance*. St. Louis, MO: Butterworth Heinemann Elsevier; 2007.
47. Durstine JL, Gordon B, Wang Z, Luo X. Chronic disease and the link to physical activity. *J Sport Heal Sci* 2013;**2**:3–11.