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ORIGINAL ARTICLE

Basketball free-throws performance depends on the integrity of binocular vision

JESÚS VERA[1], RUBEN MOLINA[1], DAVID CÁRDENAS[2], BEATRÍZ REDONDO[1], & RAIMUNDO JIMÉNEZ[1]

[1]*Department of Optics, Faculty of Sciences, University of Granada, Granada, Spain &* [2]*Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain*

ABSTRACT

Background: The deterioration of the integrity of binocular vision has a detrimental effect on fine visuomotor skills, however, its impact on sports performance remains unknown. We tested the influence of four viewing conditions (binocular viewing, monocular viewing, binocular viewing with monocular blur, and binocular viewing with binocular blur) on basketball free-throws performance.

Methods: Twenty-three male basketball players (19.2 ± 3.4 years) performed 30 free-throws in each viewing condition following a randomised order. Image degradation was induced by the use of Bangerter filters. Complementarily, perceived levels of task load and complexity, as well as visual function were assessed.

Results: We found a worse basketball free-throws performance (percentage of successful shots) in the monocular viewing (~8%) and binocular viewing with monocular blur (~9%) in comparison to the condition of binocular viewing (corrected p-values = 0.003 and 0.006; and ds = 0.838 and 0.771). The analyses of subjective ratings and visual function allowed us to confirm a successful experimental manipulation.

Conclusions: Basketball free-throws performance is subject to the integrity of binocular vision, showing a worse accuracy when the sensory dominant eye was occluded or blurred in comparison to natural (binocular) viewing conditions. However, free-throws performance remains stable when the visual acuity is binocularly degraded. Our findings reveal that an appropriate functioning of the binocular vision is needed for optimal sports performance, and highlight the importance of a comprehensive clinical assessment or management of binocular vision in sport contexts.

KEYWORDS: *Visual function, stereoacuity, sports performance, optometry, sports vision*

Highlights

- Artificially-induced binocular impairment deteriorates basketball free-throws performance.
- A lower percentage of hits was found when the sensory dominant eye was occluded or blurred in comparison to natural binocular viewing conditions.
- The assessment of the visual function and subjective ratings confirmed a successful experimental manipulation.

Introduction

An accurate functioning of the visual system is required for successful sports performance, and the visual skills needed during the game are highly dependent on the sport discipline involved (Laby, Kirschen, & Pantall, 2011). There is evidence that athletes exhibit better performance in different visual abilities, including eye-hand co-ordination, fusional vergence rate, oculomotor dynamics, reaction time and dynamic visual acuity (Piras, Lobietti, & Squatrito, 2014; Quevedo-Junyent, Aznar-Casanova, Merindano-Encina, Cardona, & Solé-Fortó, 2011; Vera, Jiménez, Cárdenas, Redondo, & Antonio, 2017; Zwierko et al., 2018).

In dynamic sports, players must be aware of static and moving objects (e.g. opponent, teammate, basket, goal, net, ball), especially in the most visually and cognitively demanding sports (Sillero, Refoyo, Lorenzo, & Sampedro, 2007). Therefore, it is plausible to expect that the limitation of visual capabilities

Correspondence: Beatriz Redondo Department of Optics, University of Granada, Campus de la Fuentenueva 2, 18001 Granada, Spain. E-mail: beadondo@gmail.com

may have a detrimental influence on sports performance. Based on this, previous studies have tested the effects of retinal defocus on performance in certain sport actions such as golf putting, cricket batting or basketball free-throw (Applegate & Applegate, 1992; Bulson, Ciuffreda, & Hung, 2008; Bulson, Ciuffreda, Hayes, & Ludlam, 2015; Mann, Ho, De Souza, Watson, & Taylor, 2007), and overall, they agree that considerable binocular blur is necessary to deteriorate athletic performance.

Nevertheless, beyond the relevance of visual acuity, a precise cortical integration of the stimuli perceived from both eyes, namely binocular vision, is required for the existence of superior visual skills (i.e. stereopsis). For acceptable levels of sports performance, an appropriate functioning of these superior visual abilities is required, especially in those sport disciplines in which the ability to judge spatial localisation accurately and discriminate distance information is needed (Erickson, 2007; Mazyn, Lenoir, Montagne, & Savelsbergh, 2004). A broad range of ocular conditions such as anisometropia, aniseikonia, cataract or glaucoma are known to provoke binocular rivalry, and thus, affect binocular vision (Blake & Wilson, 2011; Holopigian, Blake, & Greenwald, 1986; Jiménez, Ponce, & González-Anera, 2004; Jiménez, Ponce, Jiménez Del Barco, Díaz, & & Pérez-Ocon, 2002; Park, Kim, & Lee, 2018; Rutstein, Fullard, Wilson, & Gordon, 2015). Significant deficits in motor performance have been observed in abnormal binocular vision conditions (O'Connor, Birch, Anderson, & Draper, 2010), monocular viewing conditions (Gonzalez & Niechwiej-Szwedo, 2016) or degraded binocular vision (Piano & O'Connor, 2013) in different contexts. It has been argued that individuals with congenital or early deteriorated binocular function develop compensatory strategies (i.e. use of monocular cues) over time in order to circumvent this impairment (Howard & Rogers, 2002). However, to date, there are no studies that have investigated the effects on sports performance of interocular differences in the images perceived when the binocular vision is acutely altered, specifically on basketball free-throws performance. There is scientific evidence that an unequal balance between eyes is commonly presented, with this interocular imbalance having a negative impact on different visuo-motor skills (Gonzalez & Niechwiej-Szwedo, 2016; O'Connor et al., 2010; Piano & O'Connor, 2013). Therefore, we consider of interest to assess the potential detrimental effects of interocular imbalance in sports performance.

To fulfil the limitations found in the related literature, we aimed to test the association between binocular vision and basketball free-throws performance. To do this, we simulated three types of viewing conditions, using Bangerter filters (monocular viewing, binocular viewing with monocular blur, and binocular viewing with binocular blur), in experienced basketball players, and evaluated its impact on basketball free-throws performance. We hypothesised that impaired binocular vision would negatively affect basketball free-throws performance, since the acute deterioration of binocular vision limits different visual skills such as stereopsis (Costa, Moreira, Hamer, & Ventura, 2010; Odell, Hatt, Leske, Adams, & Holmes, 2009), which is known to be important in sport scenarios (Paulus et al., 2014). At the same time, we checked the influence of viewing conditions manipulation on visual acuity and stereopsis, as well as on subjective ratings of task complexity and performance. The results drawn for this study may help us to understand the relevance of preserving binocular function intact for sports performance, specifically on basketball free-throws accuracy, and highlight the importance of performing a full optometric examination to athletes in order to detect visual binocular imbalances that may potentially affect sports performance.

Methods

Participants and ethical approval

Twenty-three male amateur basketball players (regional league; fifth Spanish division) took part in this study (age [mean ± standard deviation] = 19.2 ± 3.4 years; basketball experience = 10.5 ± 4.0 years). All participants enrolled in this study fitted within the following inclusion criteria: (i) five or more years of experience in basketball competition, (ii) free of any ocular disease, (iii) present static monocular visual acuity ≤ 0 log MAR in both eyes with their best optical correction, when needed, participants wore their soft contact lenses for the experiment, and (iv) to have a near stereoacuity ≤ 50 sec of arc and far stereoacuity ≤ 60 sec of arc. The current study adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board (438/CEIH/2017).

Experimental design

We used a repeated measures design to explore the impact of binocular vision impairment on basketball free-throws performance and subjective perceptions. The success of our experimental manipulation was corroborated by the analysis of the visual function (visual acuity and far stereopsis) under the different viewing conditions. The only within-participants factor was the type of viewing condition (binocular viewing, monocular viewing, monocular impairment, and binocular impairment), and the dependent variables were free-throws performance (percentage of hits) and subjective ratings (NASA-TLX and perceived task complexity).

Viewing conditions manipulation

The four viewing conditions are illustrated in Figure 1, and they consisted in (i) binocular viewing (control condition): basketball free-throws were performed without any visual limitation, (ii) monocular viewing: the sensory dominant eye was occluded by a patch, (iii) binocular viewing with monocular retinal image degradation (monocular impairment): a Bangerter filter of a neutral density 0.2 was placed in the sensory dominant eye, and (iv) binocular viewing with degradation of both retinal images (binocular impairment): two Bangerter filters of a neutral density 0.2 were placed in both eyes. Sensory eye dominance was assessed by judgement of stimulus contrast-polarity (Bossi, Hamm, Dahlmann-Noor, & Dakin, 2018). For the purposes of this study, we chose to use the Bangerter filters since previous studies have demonstrated that they induce a significant deterioration of different visual skills (Odell et al., 2009; Odell, Leske, Hatt, Adams, & Holmes, 2008), and permit us to avoid the modification of retinal image size induced by spherical lenses. Participants with refractive errors were asked to wear soft contact lenses during the experiment.

Procedure

The experiment was carried out in two experimental sessions. In the first session, participants read and signed the consent form and filled in the demographic questionnaire. We also used this session as manipulation check, and for that purpose, we assessed far visual acuity and far stereopsis under the different viewing conditions. A polarised monitor (POLA VistaVision, DMD Med Tech SRL, Torino, Italy) situated at 5 m was used to measure visual acuity (logarithmic letters chart test employing the Bailey-Lovie design) and far stereoacuity (using a polarising viewer).

The second visit to the laboratory comprised the main experimental session, and participants performed four experimental conditions, which were carried out in randomised order across participants. The entire protocol lasted approximately 90 min, and each of the four conditions consisted in 30 free-throws (performed in series of two throws), which resulted in a total of 120 free-throws. Before the commencement of the experimental session, participants completed a standardised warm-up, consisting of ten minutes of jogging and dynamic stretching. Subsequently, they performed 20 free-throws (practice trials) as part of the warm-up. Then, participants were allowed to rest for five minutes, and three minutes of adjustment under each viewing condition were given before the first free-throw. The basketball hoop was situated at a standardised distance (4.60 m) and height (3.05 m), and the percentage of successful shots was considered for further analysis. All participants completed the experiment at the same time of the day (7 pm), and under controlled laboratory conditions (i.e. isolated from external noise, and with constant illumination and temperature). Subjective scales were administered after completing each condition, and a five-minute break was given between experimental conditions.

Subjective scales

The NASA-TLX scale was administered after each of the four experimental conditions. This scale is composed of six subscales (mental demand, physical demand, temporal demand, performance, effort and frustration), and participants had to score each subscale into 20 equal intervals anchored by a bipolar descriptor (e.g. low/high), this score was multiplied by 5, resulting in a final score of between 0 and 100. An average value from the six subscales was used (Hart & Staveland, 1988). We also asked participants to report their perceived level of task complexity after each experimental condition. It

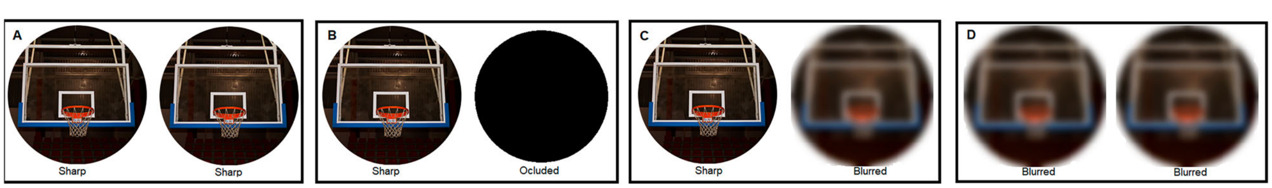

Figure 1. Overview of the different viewing conditions. Panel (A) binocular viewing, Panel (B) monocular viewing, Panel (C) monocular impairment, and Panel (D) binocular impairment.

consisted of a numerical scale (ranging from 0 to 10) defined as 0 very easy and 10 extremely difficult.

Statistical analysis

To test the impact of viewing conditions on free-throws performance, visual function and subjective perceptions, we performed separate repeated measures analyses of variance, considering the type of visual condition (binocular viewing, monocular viewing, binocular viewing with retinal image monocular degradation, and binocular viewing with both degraded retinal images) as the only within-participants factor, and with the percentage accuracy, visual acuity and far stereopsis, and subjective perceptions (NASA-TLX, and perceived difficulty) as dependent variables. The magnitude of the differences was also assessed through the Cohen's d for pairwise comparisons and the partial eta squared (η_p^2) for multiple comparisons. All statistical analyses were performed using JASP software (version 0.9.0.1). Statistical significance was set at an alpha level of 0.05, and post hoc tests were corrected using Holm–Bonferroni procedures.

Results

Table I displays the descriptive statistics of basketball free-throws performance, visual function, and subjective perceptions for each viewing condition.

For the basketball free-throws performance, there was a main effect of the type of viewing condition ($F_{3,66} = 4.713$, $p = 0.005$, $\eta_p^2 = 0.176$). Post-hoc analyses revealed that there were significant differences for the comparisons between binocular viewing and monocular viewing (corrected p-value = 0.003, d = 0.838), as well as between binocular viewing and monocular impairment (corrected p-value = 0.006, d = 0.771). However, no differences were found between the binocular viewing and binocular impairment conditions (corrected p-value = 0.522) (Figure 2). At the same time, we tested whether there was a time-on-task effect (i.e. visual impairment habituation) on basketball free-throws performance by the inclusion of each basketball free-throw (from 1 to 30) as an additional within-participants factor. This analysis showed that the main effect of time-on-task ($F_{29,638} = 0.358$, $p = 0.999$), as well as the interaction *type of visual condition x time-on-task* ($F_{87,1914} = 0.284$, $p = 0.999$) were far from showing any influence on basketball free-throws performance.

A successful experimental manipulation was confirmed by the analysis of the effect of viewing conditions on visual acuity and far stereoacuity ($F_{3,66} = 170.2$, $p < 0.001$, $\eta_p^2 = 0.866$ and $F_{2,44} = 338.9$, $p < 0.001$, $\eta_p^2 = 0.939$, respectively). Post-hoc tests for both dependent variables demonstrated that all the possible comparisons were significantly different (all corrected p-values < 0.05), with better visual acuity and stereopsis in the binocular viewing condition in comparison to the conditions in which the binocular vision was artificially impaired.

Regarding subjective perception, the NASA-TLX yielded a significant effect for the type of viewing condition ($F_{3,66} = 15.50$, $p < 0.001$, $\eta_p^2 = 0.413$), with the control condition (binocular viewing) revealing lower ratings of task load when compared with the monocular viewing (corrected p-value < 0.001, d = 1.077), monocular impairment (corrected p-value < 0.001, d = 0.918), and binocular impairment (corrected p-value < 0.001, d = 0.970). Similarly, perceived task complexity was demonstrated to be sensitive to viewing conditions manipulation ($F_{3,66} = 20.68$, $p < 0.001$, $\eta_p^2 = 0.496$), and showed statistically significant differences for the comparisons between control condition and monocular viewing (corrected p-value < 0.001, d = 1.391), monocular impairment (corrected p-value < 0.001, d = 1.269), and binocular impairment (corrected p-value < 0.001, d = 1.543) conditions.

Discussion

The present study demonstrated that basketball free-throws performance was sensitive to artificially induced binocular vision impairment, specifically when the dominant eye is occluded or the image from the dominant eye is degraded. Nevertheless,

Table I. Descriptive values (mean ± standard deviation) of free-throws performance, subjective perceptions and visual function in each viewing condition.

	Binocular viewing	Monocular viewing	Monocular impairment	Binocular impairment
Free-throws accuracy (%)	69.7 ± 17.0	61.6 ± 19.8	60.7 ± 19.7	64.9 ± 22.4
NASA-TLX	29.9 ± 14.1	41.8 ± 13.9	38.0 ± 14.8	39.8 ± 13.8
Perceived complexity	2.6 ± 1.8	5.5 ± 2.2	5.1 ± 2.5	5.5 ± 2.2
Visual acuity (logMAR)	−0.14 ± 0.06	−0.09 ± 0.08	0.34 ± 0.07	0.25 ± 0.10
Stereopsis (sec of arc)	37.82 ± 20.66	–	206.09 ± 39.74	229.57 ± 50.04

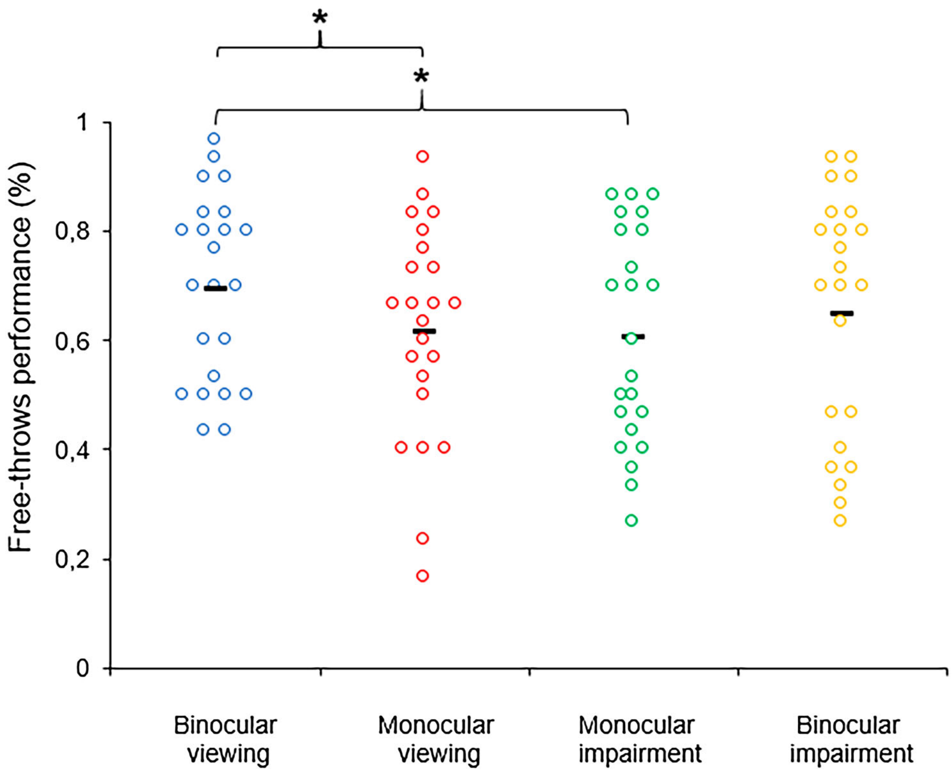

Figure 2. Scatterplot of the different viewing conditions on basketball free-throw performance. The horizontal lines indicate the average value, and * represents statistically significant differences between two viewing conditions (corrected p-value < 0.05).

binocular defocus did not have a significant impact on hits accuracy of free-throws in experienced basketball players. Our data are in line with the fact that sports performance in different sport disciplines (i.e. golf putting, basketball free-throw, cricket batting) is resilient to moderate levels of binocular image degradation (Applegate & Applegate, 1992; Bulson et al., 2015, 2008; Mann et al., 2007; Mann, Abernethy, & Farrow, 2010). These findings incorporate preliminary evidence on the role of binocular vision in sports performance, even in non-complex and static situations.

Previous research has focused on the effect of binocular spherical and astigmatic retinal defocus on athletic performance (Applegate & Applegate, 1992; Bulson et al., 2015, 2008; Mann et al., 2007). Nevertheless, there are no studies that have explored the importance of interocular blur differences in sports performance, and it may be of special relevance due to the number of visual conditions (e.g. anisometropia or aniseikonia) in which the binocular function is deteriorated as a consequence of two dissimilar monocular images. There is accumulated evidence that athletes, especially in ball sports, may benefit from highly developed stereopsis, and on the contrary, they may see significantly deteriorated their performance in fine visuomotor tasks by degrading the ability of depth perception(O'Connor et al., 2010), as it may be the case found in the current study with basketball free-throws.

Multiple factors are known to play a role on the link between binocular inhibition and task performance. In this regard, task complexity is known to modulate the impact of reduced binocular function on visuomotor tasks performance, with easy tasks being more resilient to binocular vision deterioration (Piano & O'Connor, 2013). Of note, we found that the manipulation of the binocular vision had an effect on perceived levels of task complexity, with participants reporting greater levels of task load in those experimental conditions in which the binocular vision was artificially impaired. These results are of relevance since higher levels of perceived anxiety or mental load are known to have a negative influence on sports performance (Englert & Bertrams, 2012; Jokela & Hanin, 1999), and thus, it is plausible to expect that the deterioration of perceptual skills may contribute to the relationship between mental load and sports performance. Nevertheless, it should be emphasised that basketball free-throws shooting is performed in fixed conditions (static task), and its automation depends on the repeated practice (Ripoll, Bard, & Paillard, 1986). Thus, in more challenging situations (e.g. dynamic actions with intense defensive pressure), the deterioration of binocular balance may show a heightened effect on sports performance, since dynamic stereopsis has been identified as an important component in dynamic sports (Solomon, Zinn, & Vacroux, 1988).

Taken together, our results corroborate the idea, by the analysis of the visual function under the different viewing conditions, that binocular rivalry negatively affects binocular function and it seems to have a direct impact on basketball free-throws performance. Interocular differences in the level of blur have a high prevalence worldwide (Weakley Jr, 2001), and importantly, the visual system is biased by the sharper of the two eyeś retinal images (Kompaniez, Sawides, Marcos, & Webster, 2013). In this study, this fact was supported by the impact of viewing conditions on binocular visual acuity, with better visual acuity when only the image from one was blurred (-0.02 ± 0.12 logMAR) in comparison with the binocular blur condition (0.25 ± 0.10 logMAR). Moreover, our results indicate that a good binocular visual acuity may not be enough to ensure basketball free-throws performance, being in accordance with the study of Applegate and Applegate (1992), in which a decrease in binocular visual acuity over range 6/6 to 6/75 did not significantly reduce the basketball free-throws efficiency. Additionally, in our study the basketball free-throws performance was significantly reduced when the dominant-eye was occluded or blurred, and therefore it would be plausible to think that the lack or deterioration of stereopsis could be the main cause for a worst free-throws accuracy, since numerous monocular relative depth cues (motion parallax, linear perspective, relative size, shading and shadows, and texture gradient) that are used simultaneously with the binocular cues are insufficient to accurately determine the absolute depth when the binocular function is altered (McKee & Taylor, 2010).

Here, we induced an interocular imbalance by using neutral density filters, however, there is scientific evidence that some individuals, including non-clinical population, are strongly imbalanced (Zhang, Bobier, Thompson, & Hess, 2011), which it could lead to a limited binocular function, as consequence of an unequal contribution from each eye. In view of this, the determination of considerable interocular differences (i.e. unequal contribution of each eye) may be of relevance in sport contexts, since a preserved binocular balance seems to be beneficial in terms of free throws accuracy. In addition, there are several visual therapy techniques such as dichotopic training, perceptual learning, non-invasive brain stimulation or monocular deprivation that have demonstrated to contribute to improving the binocular balance (Hess & Thompson, 2015; Kim, Kim, & Blake, 2017), however, the possible utility of these procedures in order to enhance the binocular function of athletes from different disciplines needs to be addressed in further investigations.

There are some aspects that may limit the present findings and we must acknowledge. First, our experimental sample was formed by experienced basketball players, and the short-terms effects of blur manipulation in athletic performance have demonstrated to vary between skilled and less-skilled athletes (Ryu, Abernethy, Mann, & Poolton, 2015), and therefore the external validity of the current findings should be tested in basketball players with different levels of expertise. Second, we chose to test the effects of visual function deterioration on a static task and at a fixed distance, and as indicated in previous investigations, the current findings may be more evident in dynamic situations and at other distances (e.g. three point line). Third, the deterioration of the binocular function is dependent on the degree of interocular difference (Pardhan & Gilchristt, 1990; Piano & O'Connor, 2013). Here, we induced a blur difference between eyes of approximately six lines of visual acuity, and the influence of different levels of monocular defocus on sports performance should be address in future investigations. We consider that future studies should explore the interocular differences tolerance for sports performance, as well as the possible factors that may play a mediating role in these effects, and it would allow to determine which levels of binocular imbalance may have a relevant impact on sports performance. Fourth, blur tolerance is subject to a great inter-subject variability (Vera-Diaz, Woods, & Peli, 2010), and therefore, the binocular function of two individuals may be differently affected by the same degree of interocular difference. Therefore, this factor may be taken into account in future studies. Fifth, in the present study only the participant's dominant eye was occluded or blurred, and although the effects of blurring the dominant or non-dominant eyes on stereopsis have not been clearly established (Nabie, Andalib, Amir-Aslanzadeh, & Khojasteh, 2017). Further studies are needed in order to clarify whether the deterioration of the non-dominant may result in some different effects on eye-hand coordination, which is known to play an important role on basketball free-throws accuracy (Krause & Nelson, 2018). Lastly, only males were included in this study, and the generalizability of the current findings in women needs further investigation.

In conclusion, artificially induced binocular impairment, specifically both monocular occlusion and monocular blur in the sensory dominant eye, negatively affects basketball free-throws performance, contrasting with the blur binocular condition in which the percentage of hits was not significantly diminished in comparison with natural binocular viewing. Based on the present outcomes, the visual function of athletes should be thoroughly assessed by eyecare specialists in order to ensure an appropriate sports performance. It would be of interest to investigate the effects of binocular vision impairment on sports performance in dynamic actions and for different positions occupied by players on the field (e.g. throws from three-point line, ball catching and ball passes).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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