Article ▸ Interpupillary Distance and Pupil Diameter of Baseball Athletes and Non-athletes

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ABSTRACT

Purpose: To examine whether differences exist in interpupillary distance (IPD) and pupil diameter (PD) between professional baseball players compared to non-athletes (males and females).

Methods: 149 Major League Baseball (MLB) athletes and 416 non-athletes (NA) were examined on the RightEye IPD/PD test. One-way analysis of variance with Levene tests for testing assumption of variances were performed. If assumptions were violated, the Kruskal-Wallis test was used to analyze group differences with Tukey and Dunnett (T3) post-hoc tests. Alpha was set to $p < 0.05$.

Results: For IPD, there was a significant difference ($p < 0.0005$) between female non-athletes, male non-athletes, and MLB players. IPD did not meet the assumption of homogeneity of variance ($p < 0.0005$). Post-hoc tests indicated that for IPD, all three groups were significantly different from one another. Female non-athletes had the smallest IPD. Male non-athletes had a larger IPD than female athletes. MLB players had the largest IPD. For PD, there was a significant difference (< 0.0005) between female non-athletes, male non-athletes, and MLB players. Post-hoc tests indicated that for PD, male and female non-athletes were not significantly different from one another. MLB players were, however, significantly different from female non-athletes and from male non-athletes. Both male and female non-athletes had a larger PD than MLB players.

Conclusions: Past research has shown that IPD and PD affect important visual skills needed for playing baseball, such as stereo acuity, convergence, accommodation, and image quality. Differences in IPD and PD may provide another component in the equation that determines success.

Keywords: athletic performance, depth perception, vision, visual acuity

Introduction

Distance between the pupils, called interpupillary distance (IPD), is an important clinical measure used to identify potential vision issues such as stereo acuity,[1] near point of convergence,[2] accommodation,[3] and other vision related issues.[4] IPD is measured using the distance between the centers of the pupils.[5,6]

The diameter of the pupil (PD) is another important clinical measure of the eye and is related to image quality. A larger pupil will allow more peripheral rays into the eye, resulting in high-order monochromatic aberrations and posing a problem with image quality when the PD is large.[7] A limitation of very small pupils can be diffraction; however, this problem is

less significant than the aberrations seen with larger pupil sizes, as demonstrated by Howland and Howland.[8] Depth of focus is related to pupil size. Smaller pupils allow an increase in depth of focus, which in turn reduces the effect of refractive errors and errors in accommodation such as accommodative lag on the quality (blur) of the retinal image.[9]

Various anthropometric databases exist examining IPD and PD. Past normative data using the RightEye IPD/PD test has shown that males, on average, have larger IPDs than females.[10] This is consistent with other databases, specifically the Military Handbook 743A and work by Dodgson[11] and Smith and Atkinson.[12]

Studies of the difference in pupil size between males and females have shown mixed results in past research. Poynter[13] found significant differences in pupil size between males and females, with females having larger pupil sizes than males. However, no significant differences were found in pupil size between genders in a study by Hashemian et al.[14] These inconsistent results may be due to experimental design, including different tasks, emotional and cognitive loads, and mesopic conditions. Further research between pupil size and gender is needed.

IPD and PD influence many vision components that are important in sport, specifically in baseball. For instance, IPD determines the amount of stereo separation of two images that are combined in the brain to produce stereo perception.[11,15] Stereo perception is important in the rapid 3-dimensional processing involved in catching a ball, for instance. A wider IPD has a greater angle of disparity, resulting in greater stereo acuity.[16-18]

Frisby et al.[16] identified a positive linear correlation between IPD and stereo acuity when testing 109 students who had normal vision. Lam et al.[17] found that smaller IPD resulted in decreased stereo acuity. In a study with optically widened IPDs, stereoscopic ability improved with an increase in pupil distance.[18] Taken together, these studies lend support to the intuitive idea that a larger IPD would mean better stereo acuity than would a smaller IPD. Based on current research that suggests that athletes tend to display enhanced stereo acuity, coupled with the results of studies supporting the influence of IPD on stereo acuity, it is reasonable to assume that stereo acuity is a function of IPD. This begs the question: Do baseball players have a larger IPD than non-baseball players?

Quality of the visual image, depth perception, dynamic visual acuity, and field of view are other important components in a fast-moving sport such as baseball.[19] The size of the pupil is related to image quality.[7] Smaller PD can reduce aberrations and improve depth of focus.[9] Given that visual image and depth perception is related to PD, and in turn these are critical visual components to baseball, this too begs the question: Do baseball players have a larger PD than non-baseball players?

The purpose of this study is to examine whether differences exist in IPD and PD between professional baseball players compared to non-athletes (males and females).

Methods
Participants
One hundred forty-nine Major League Baseball (MLB) athletes and 416 non-athletes (NA) were selected for this study through a program of visual testing using eye tracking equipment. All MLB athletes were on MLB teams. The average batting average and on-base percentage were 0.272 (SD = 0.03) and 0.335 (SD = 0.04), respectively. They played an average of 4.2 (SD = 1.5) years in the major leagues. Non-athletes comprised 189 (45%) males and 227 (55%) females. MLB athletes were between the ages of 26 and 31 years (M = 28.1, SD = 3.2), and NA participants were between the ages of 19 and 35 years (M = 27.1, SD = 5.1).
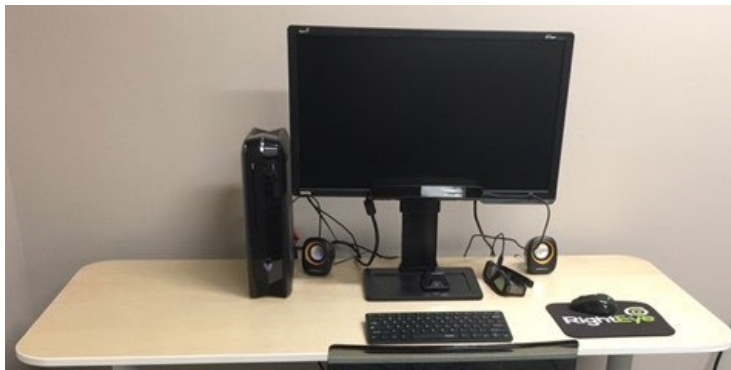
Figure 1. *RightEye set up*

Figure 2. *Stimuli*

Participants were excluded from participation in the study if they met any of the following pre-screening conditions:
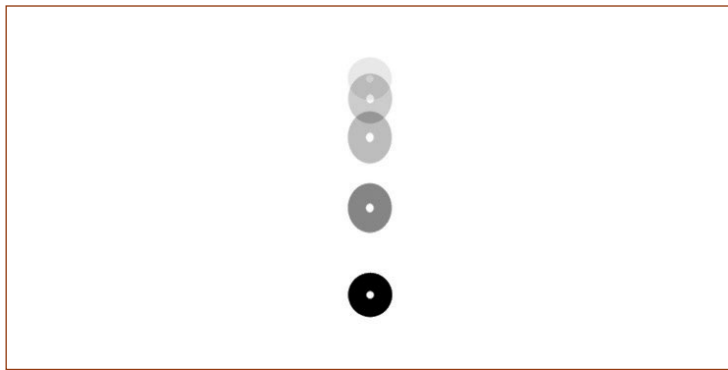
- neurological disorders (such as concussion, traumatic brain injury, Parkinson's Disease, Huntington's Disease, cerebral palsy)
- vision-related issues that prevented successful calibration[20,21] of all 9 points (such as extreme tropias, phorias,[22,23] static visual acuity of less than 20/400,[20] nystagmus,[20,23] cataracts,[24] or eyelash impediments[24])
- small vessel strokes
- consumption of drugs or alcohol within 24 hours of testing

All participants provided informed consent to participate in this study in accordance with IRB procedure (IRB: UMCIRB 13-002660).

All testing was conducted by vision specialists (e.g., optometrists, ophthalmologists). RightEye testing was performed by those who had received and passed the RightEye training, education, and protocol procedures prior to testing.

Materials and Equipment

For the RightEye IPD/PD test, the participant was seated in a stationary (non-wheeled) chair that could not be adjusted in height at a desk within a quiet, private testing room (Figure 1). The participant was asked to look at a NVIDIA 24-inch 3D Vision monitor that could be adjusted in height, which 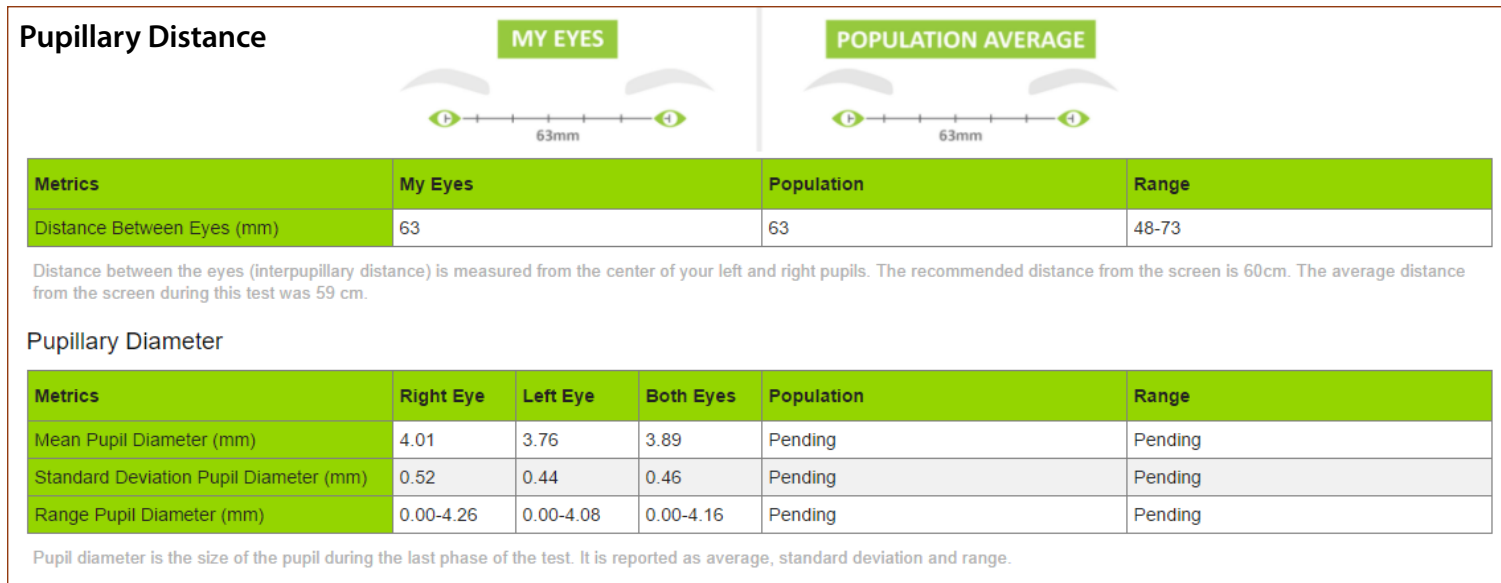was fitted with an SMI 12" 120 Hz remote eye tracker connected to an Alienware gaming system and a Logitech (model Y-R0017) wireless keyboard and mouse. Screen luminance was 85cd/m2, and room luminance with the lights on was 344cd/m2. Participants' heads were unconstrained during the test, although they were instructed to sit still. The system has no restrictions in range when calculating IPD or PD.

The eye tracker is used to capture the x and y coordinates for each eye, along with the z-distance at 120 times per second. Once the stimulus is at the center point of the screen (960 x 540), the eye tracker detects whether the eye is looking at the stimulus. Once confirmed, the first sample of data is used to measure IPD. Then, using the x and y eye coordinates in 3D space for the left and right eye, the participant's IPD is calculated.

PD measurements are taken at the same time as IPD measurements in the RightEye IPD/PD test. For a 120 Hz eye tracker, output is reported every 8 milliseconds. Using the center point of the screen, 700 milliseconds of data is collected, resulting in a sample of 87 data points. These metrics are then used to calculate average pupil size, range, and standard deviation of both left and right eye. Size of the pupil is determined by the contour of the pupil.

Testing Procedure

The RightEye IPD/PD test involved participants positioning themselves in front of the eye tracking system, measured at an exact distance of 60cm from the eye tracker (ideal

Pupillary Distance

Metrics	My Eyes	Population	Range
Distance Between Eyes (mm)	63	63	48-73

Distance between the eyes (interpupillary distance) is measured from the center of your left and right pupils. The recommended distance from the screen is 60cm. The average distance from the screen during this test was 59 cm.

Pupillary Diameter

Metrics	Right Eye	Left Eye	Both Eyes	Population	Range
Mean Pupil Diameter (mm)	4.01	3.76	3.89	Pending	Pending
Standard Deviation Pupil Diameter (mm)	0.52	0.44	0.46	Pending	Pending
Range Pupil Diameter (mm)	0.00-4.26	0.00-4.08	0.00-4.16	Pending	Pending

Pupil diameter is the size of the pupil during the last phase of the test. It is reported as average, standard deviation and range.

Figure 3. RightEye IPD/PD report

positioning within the head box range of the eye tracker) for standardization before testing. A 9-point calibration test was conducted with points spanning the computer screen. Participants were required to pass all 9 points before proceeding with testing.

Upon successful calibration, the RightEye IPD/PD test commenced. The subject read the following instructions: "Follow the dot from the top of the screen to the center. Watch the dot get smaller, and keep looking at it until it disappears. Keep your eyes still and focused when the dot stops in the center of the screen." When instructions are read, the user proceeds to the test, where a dot drops from the top center of the screen to the middle of the screen. Once in the middle of the screen, the dot stops and shrinks in size over a 700-millisecond period (Figure 2).
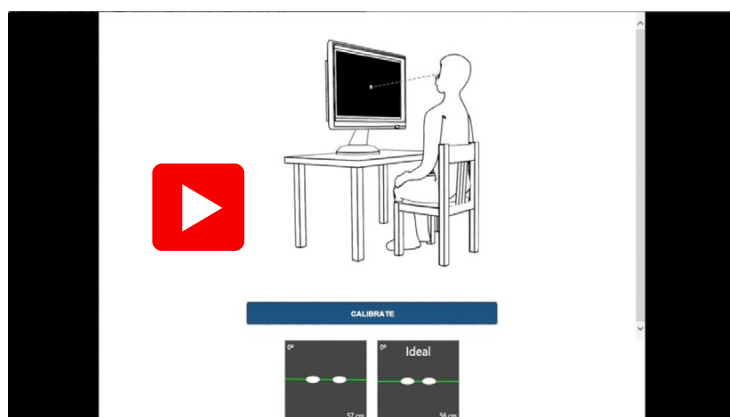
Video: RightEye calibration test.

After completing the test, a report shows both the IPD and PD results (Figure 3).

Validity by Design

Validity by design, also known as "face validity" or "a priori validity," is concerned with whether a test actually measures what it claims to measure. The RightEye IPD/PD Test has several validity-by-design elements build into the test. These fall into two categories, test stimulus and testing protocol.

Test Stimulus: To obtain accurate IPD, the stimulus must be presented in the center of the screen without deviation from one test to the next. This is obtained through computer programming allowing the participant to see the same exact stimulus every time the test is conducted. Furthermore, the initial drop of the stimulus (movement), time, and size reduction of the stimulus encourages the participant look at the stimulus during the test.

To obtain accurate PD, the luminance level on the screen must remain consistent, both during the test and between tests. To ensure that this occurs, screen luminance is pre-set via software code that prevents any adaptations by a participant or tester. In this experiment, room luminance was controlled by testers who tested in the same location every time and who were asked to set the room with the lights on

Table 1. Summary of Clinical Findings for Both Cases

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
IPD	Female Nonathletes	227	61.54	2.66	0.18	61.19	61.88	54.00	66.32
	Male Nonathletes	189	64.32	1.50	0.11	64.11	64.54	59.03	68.74
	MLB Players	149	69.91	2.38	0.20	69.52	70.29	66.10	74.97
	Total	565	64.68	4.04	0.17	64.34	65.01	54.00	74.97
PD	Female Nonathletes	29	3.58	0.27	0.05	3.47	3.68	2.91	4.03
	Male Nonathletes	33	3.57	0.31	0.05	3.46	3.68	3.05	4.12
	MLB Players	195	3.09	0.29	0.02	3.05	3.13	2.08	3.68
	Total	257	3.20	0.36	0.02	3.16	3.25	2.08	4.12

Table 2. ANOVA Tables for IPD and PD

		Sum of Squares	df	Mean Square	F	Sig.
IPD	Between Groups	6337.22	2	3168.61	621.50	0.001
	Within Groups	2865.26	562	5.10		
	Total	9202.48	564			
PD	Between Groups	11.09	2	5.54	64.81	0.001
	Within Groups	21.73	254	0.09		
	Total	32.81	256			

and blinds covering the windows in order to obtain the same luminance level (344cd/m^2).

Test protocol: To ensure accuracy of IPD and PD, it is important that three conditions are met: a) the distance from the screen is 60cm, b) the eyes remain stationary during the last 700 milliseconds, and c) the participant looks at the stimulus. To assist with these conditions, a chin rest is recommended for younger patients or for those with certain movement-related disorders. Additionally, error handling is employed, using the eye tracker to determine the location of the participant's eyes on the screen, ensuring that he/she is looking at the target during the last 700 milliseconds when IPD and PD are being calculated. Error proofing is also included for distance from the screen, where the participant will be forced to retest if they move outside the required 60cm during the testing time. If this occurs, an error message will let the tester know, and the test will be redone. This further enhances the confidence that the participant was confirmed as "on the stimulus" when the calculations were made.

Furthermore, to ensure overall testing accuracy, the two examiners were trained on how to run each test with accuracy and consistency and were given one hour of dedicated training. This concluded with a test in the form of a demonstration to an experienced tester, requiring a "passing" grade prior to testing any participants.

Data Analysis

Two sets of analyses were conducted. Preliminary analyses examined skewness and kurtosis for IPD and PD and provided descriptive statistics for the two variables, including means, standard deviations, standard errors, confidence intervals, minimum values, and maximum values. Main analyses examined group differences in IPD and PD. Specifically, one-way ANOVAs analyzed differences in IPD and PD between female non-athletes, male non-athletes, and MLB players. The assumption of homogeneity of variances across groups was tested using the Levene test. If assumptions were violated, Kruskal-Wallis tests analyzed
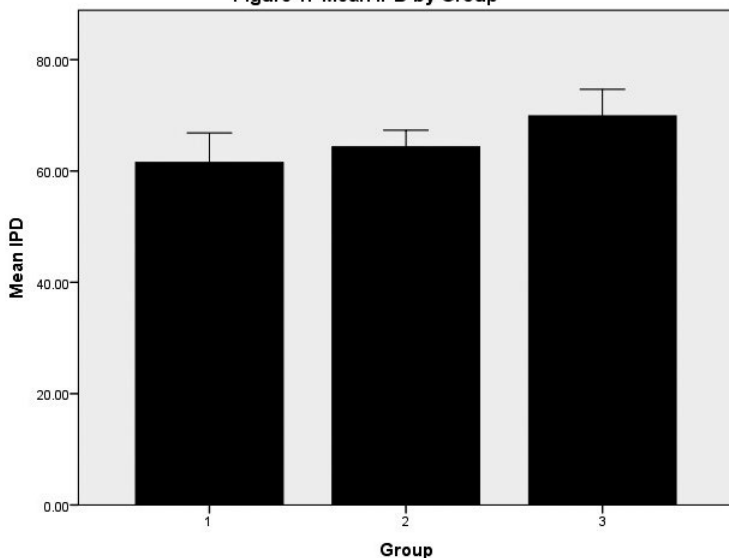
Figure 1. Mean IPD by Group

Figure 2. Mean PD by Group

Figure 4. Mean IPD per group. Group 1 Female, Group 2 Male, Group 3 athlete.
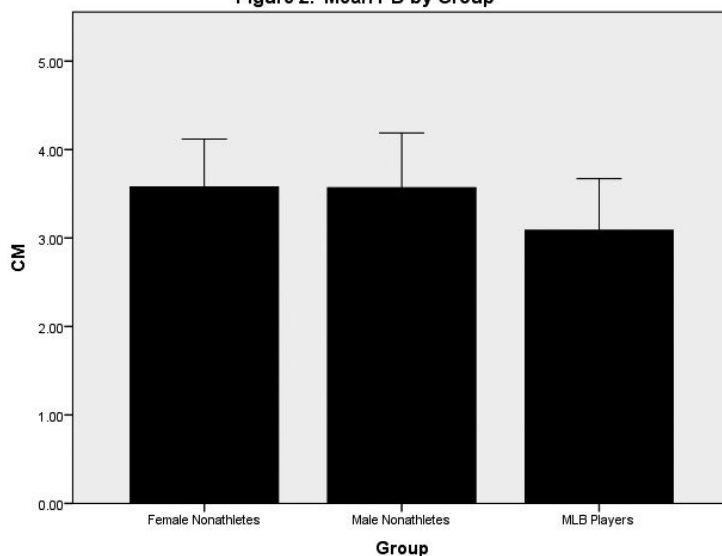
Figure 5. Mean PD per group. Group 1 Female, Group 2 Male, Group 3 athlete.

Table 3. Post Hoc Tests IPD and PD. * The mean difference is significant at the 0.05 level.

Dependent Variable				Mean Difference (I-J)	Std Error	Sig	95% Confidence Interval	
							Lower Bound	Upper Bound
IPD	Tukey HSD	Male Nonathletes	Male Nonathletes	-2.79*	0.22	0.0005	-3.31	-2.26
			MLB Players	-8.37*	0.24	0.0005	-8.93	-7.81
		Female Nonathletes	Female Nonathletes	2.79*	0.22	0.0005	2.26	3.31
			MLB Players	-5.58*	0.25	0.0005	-6.16	-5.00
		MLB Players	Female Nonathletes	8.37*	0.24	0.0005	7.81	8.93
			Male Nonathletes	5.58*	0.25	0.0005	5.00	6.16
	Dunnett T3	Male Nonathletes	Male Nonathletes	-2.79*	0.21	0.0005	-3.28	-2.29
			MLB Players	-8.37*	0.26	0.0005	-9.00	-7.74
		Female Nonathletes	Female Nonathletes	2.79*	0.21	0.0005	2.29	3.28
			MLB Players	-5.58*	0.22	0.0005	-6.12	-5.05
		MLB Players	Female Nonathletes	8.37*	0.26	0.0005	7.74	9.00
			Male Nonathletes	5.58*	0.22	0.0005	5.05	6.12
PD	Tukey HSD	Male Nonathletes	Male Nonathletes	0.01	0.07	0.9937	-0.17	0.18
			MLB Players	.49*	0.06	0.0005	0.35	0.63
		Female Nonathletes	Female Nonathletes	-0.01	0.07	0.9937	-0.18	0.17
			MLB Players	.48*	0.06	0.0005	0.35	0.61
		MLB Players	Female Nonathletes	-.49*	0.06	0.0005	-0.63	-0.35
			Male Nonathletes	-.48*	0.06	0.0005	-0.61	-0.35
	Dunnett T3	Male Nonathletes	Male Nonathletes	0.01	0.07	0.9994	-0.17	0.19
			MLB Players	.49*	0.05	0.0005	0.35	0.63
		Female Nonathletes	Female Nonathletes	-0.01	0.07	0.9994	-0.19	0.17
			MLB Players	.48*	0.06	0.0005	0.34	0.63
		MLB Players	Female Nonathletes	-.49*	0.05	0.0005	-0.63	-0.35
			Male Nonathletes	-.48*	0.06	0.0005	-0.63	-0.34

group differences. Significant between-group differences were followed up with Tukey and Dunnett (T3) post-hoc tests. Alpha was set at $p < 0.05$ for all analyses.

Results

Both IPD and PD appeared to be normally distributed. That is, skewness and kurtosis were less than +/- 1 for both variables. Table 1 presents descriptive statistics for IPD and PD, including means, standard deviations,

confidence intervals, minimum values, and maximum values.

One-way ANOVAs examined differences in IPD and PD across groups. Table 2 presents F statistics and p-values for these tests.

For IPD, there was a significant difference ($F_{(2, 562)} = 621.50$, $p < 0.0005$, $\eta2 = 0.69$) between female non-athletes, male non-athletes, and MLB players. IPD did not meet the assumption of homogeneity of variance ($p < 0.0005$). Consequently, the Kruskal-Wallis test was also used to examine differences in IPD by group. There was a significant difference in the IPD distributions between female non-athletes, male non-athletes, and MLB players ($H_{(2, 565)} = 405.77$, $p < 0.0005$). Post-hoc tests, provided in Table 3, indicated that for IPD, all three groups were significantly different from one another.

Female non-athletes had the smallest IPD (Figure 4). Male non-athletes had a larger IPD than female non-athletes. MLB players had the largest IPD. That is, the MLB players had a larger IPD than both male and female non-athletes.

For PD, there was a significant difference ($F_{(2, 254)} = 64.81$, $p < 0.0005$, $\eta2 = 0.34$) between female non-athletes, male non-athletes, and MLB players (Figure 5).

ID met the assumption of homogeneity of variance ($p = 0.65$). Post-hoc tests, provided in Table 3, indicated that for PD, male and female non-athletes were not significantly different from one another. MLB players were, however, significantly different from both male and female non-athletes. Both male and female non-athletes had a larger PD than MLB players.

Discussion

The aim of this study was to determine whether a difference existed in IPD between professional baseball players and the non-athlete population. To determine that differences were not due to the reliability or validity of the test or test-taking procedure, the same process that was used in past research by Murray, Hunfalvay, and Bolte (in press)[10] was employed here. Using this process resulted in high test reliability and accuracy, therefore providing confidence that the results were not due to a lack of test consistency or accuracy.

The results from this study indicate that significant differences in IPD exist between women, men, and MLB athletes. Females had the smallest IPD (M = 61.54, SD = 2.66), male non-athletes' IPDs were larger than females' but smaller than MLB athletes' (M = 64.32, SD = 1.50), and MLB athletes had the largest IPDs (M = 69.91, SD = 2.38). These findings are consistent with past research in IPD, where non-athlete males and females were found to have differences in mean IPD.[11,12]

Significant differences in IPD were found between non-athletes (males and females) and the MLB (athlete) group. IPD influences many vision components that are important in sport, specifically in baseball, including the amount of stereo separation of two images that are combined in the brain to produce stereo perception.[11,15] Stereo perception is important in the rapid 3-dimensional processing involved in catching a ball, for instance. A wider IPD has a greater angle of disparity, resulting in greater stereo acuity.[18,25-27] It has been identified that athletes have greater stereo acuity than non-athletes. After reviewing results from this study, one possible explanation may be IPD. These findings may lead to future research investigating whether young athletes who have a wider IPD experience more success in sport due to enhanced stereo acuity. IPD is not fully developed until 19 years old in males and 14 years old in females;[28] therefore, it is important that those involved in working with athletes (ophthalmologists, optometrists, coaches, and parents) be aware that this may affect performance. The results of this study also suggest that for adult professional baseball players, IPD may be one factor in elite-level performance.

Past research was inconsistent in determining non-athlete gender differences in PD. The results of this study found that male and female non-athletes were not significantly different from one another in post-hoc testing. These results are consistent with Hashemian et al.,[14] who found no significant difference in PD between gender. Interestingly however, this study also found significant differences between non-athletes and MLB pupil size. A smaller PD size has been shown to improve image quality, as it limits diffraction[7] as well as depth of focus.[9] Both image quality and depth of focus are very important attributes when playing baseball. Past research has shown that expert baseball players often look for the pitcher's rotation at the elbow and hand placement[28] and look to track the ball visually, including the rotation of the ball detected by looking at the seams, when batting.[29] Placement of the hand on and rotation of the ball at 60 feet 6 inches away may be affected by image quality. The ability to track a ball at 95 miles per hour with rapid changes in depth is clearly related to depth of focus. The results of this study suggest that a significantly smaller PD for MLB players compared to non-athletes may be a factor in their success.

Future studies should consider ethnicity as a variable in examining IPD and PD in athletes and non-athletes. Not making a link between IPD, PD, and performance statistics within the baseball group is a limitation of this study. Future studies should examine whether those within the MLB group differ from one another on IPD and PD and whether those differences are statistically relevant when compared with performance outcomes such as on-base percentage and batting average, for example.

Taken together, MLB athletes showed significantly wider IPD and significantly smaller PD compared to non-athletes (males and females). Past research has shown that these biological structures affect important visual skills needed for playing baseball.

Baseball performance depends on a multitude of skills, techniques, and abilities, some learnt and some innate. Obviously, IPD and PD, along with athletes' visual skills, are only part of overall performance. However, when the blink of an eye can affect the ability to see a ball,[30] seemingly small differences in biological make-up like IPD and PD may provide another component in a long equation that determines success.

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