IPD comparing MLB to non-athletes

Interpupillary Distance and Pupil Diameter of Baseball Athletes and Non-Athletes

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Abstract

**Purpose.** To examine if differences occur 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. If assumptions were violated, Kruskal-Wallis test used to analyze group differences with Tukey and Dunnett (T3) post hoc tests. Alpha set to p<0.05.

**Results.** For IPD, there was a significant difference, ($p < 0.0005$) between female nonathletes, male nonathletes, 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 nonathletes had the smallest IPD. Male nonathletes had a larger IPD than female athletes. MLB players had the largest IPD. For PD, there was a significant difference, ($p < 0.0005$) between female nonathletes, male nonathletes, and MLB players. Post hoc tests, indicated that, for PD, male and female nonathletes were not significantly different from one another. MLB players were, however, significantly different from female nonathletes and from
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male nonathletes. Both male and female nonathletes had a larger PD than MLB players.

Conclusions. Past research has shown 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 the equation that determines success.

Keywords: Vision (D014785), visual acuity (D014792), depth perception (D003867), athletic performance (D054874)
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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 convergence\(^2\) and accommodation\(^3\) and other vision related issues\(^4\). IPD is measured using the distance between the centers of the pupils\(^5,6\).

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 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 in larger pupil sizes as demonstrated by Howland and Howland (1997)\(^8\). 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 males, on average, have larger IPD’s than females\(^10\). This is consistent with other databases, specifically the Military Handbook 743A and work by Dodgson (2004)\(^11\) and Smith & Atkinson (1997)\(^12\).

Differences in pupil size between males and females has shown mixed results in past research. Poynter (2016)\(^13\) 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, Soleimani, Foroutan, Joshaghani, Ghaempanah et al. (2012)\(^14\). These inconsistent results may be due to experimental design, including different tasks, emotional and cognitive loads as well as mesopic conditions. Further research between pupil size and gender is needed.
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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 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\(^{16,17,18}\).

Frisby et al. (2004)\(^{16}\) identified a positive linear correlation between IPD and stereo acuity when testing 109 students who had normal vision. Lam et al. (2008)\(^{17}\) 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 individuals with a smaller IPD. Based on current research that suggests 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. Which 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\(^{19}\). 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 if differences occur in IPD and PD between professional baseball players compared to non-athletes (males and females).

**Method**

**Participants**
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149 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 was 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 of 189 (45%) males and 227 (55%) females. MLB athletes were between the ages of 26-31 years (M = 28.1, SD = 3.2) and NA participants were between the ages of 19-35 years (M = 27.1, SD = 5.1).

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\(^{23}\), static visual acuity of greater than 20/400\(^{20}\), nystagmus\(^{20,23}\), cataracts\(^{24}\) or eye lash 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) and, in the case of RightEye testing, had received and passed the RightEye training, education, and protocol procedures prior to testing.

**Materials and Equipment**

For testing of the RightEye IPD/PD test, the participants were seated in a stationary (non-wheeled) chair that could not be adjusted in height at a desk within a quiet, private testing room (see Figure 1). The participants were 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.
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and mouse. Screen luminance was 85cd/m2, 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.

<<Insert Figure 1 here>>

The eye tracker is used to capture the x and y coordinates for each eye, along with the z-distance at 120 times a second. Once the stimulus is at the center point of the screen (960 x 540) then the eye tracker detects if the eye is looking at the stimuli, 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 participants IPD is calculated.

PD measurements are taken at the same time as IPD measurements in the RightEye IPD/PD test. For a 120-hertz 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 (ideal positioning within the head box range of the eye tracker) from the eye tracker for standardization before testing. A nine-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 as 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 drop 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 (see Figure 2).

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

Validity by Design

Validity by design also considered “face validity” or “priori validity” is concerned with whether the test seems to measure what is being claimed. The RightEye IPD/PD Test has several validity by design elements build into the test. This fall into two categories, 1. test stimuli; 2. testing protocol.

Test Stimuli: To obtain accurate IPD the stimuli 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 stimuli every time the test is conducted. Furthermore, the initial drop of the stimuli (movement), time, and size reduction of the stimuli encourages the participant look at the stimuli 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 this occurs screen luminance is pre-set via software code that prevents any adaptations by a participant or tester. Room luminance was controlled by testers who a) tested in the same location every time, b) and who was asked to set the room with the lights on and blinds covering windows in order to obtain the same luminance level (344cd/m²).

Test protocol: To ensure accuracy of IPD and PD it is important that three conditions are met: a) distance from the screen is 60cm, b) the eyes remain stationary during the last 700-
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milliseconds, c) the participant look at the stimuli. To assist with these conditions a chin rest is
recommended for younger patients or those with certain movement related disorders.

Additionally, error handling, is employed using the eye tracker to determine the location of the
participants’ eyes on the screen, ensuring they are 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 does not occur 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 stimuli” target 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 is given one-hour of dedicated training. This
is 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 nonathletes, male
nonathletes, 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
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
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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.

<<Insert Table 1 here>>

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

<<Insert Table 2 here>>

For IPD, there was a significant difference, $F(2, 562) = 621.50$, $p< 0.0005$, $\eta^2 = .69$ between female nonathletes, male nonathletes, 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 nonathletes, male nonathletes, 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.

<<Insert Table 3 here>>

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

<<Insert Figure 4 here>>

For PD, there was a significant difference, $F(2, 254) = 64.81$, $p< 0.0005$, $\eta^2 = .34$ between female nonathletes, male nonathletes, and MLB players (see Figure 5).

<<Insert Figure 5 here>>
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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 nonathletes were not significantly different from one another. MLB players were, however, significantly different from female nonathletes and from male nonathletes. Both male and female nonathletes had a larger PD than MLB players.

Discussion

The aim of this study was to determine if a difference existed in IPD between professional baseball players and the nonathlete population, both males and female nonathletes. 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 & Bolte (in-press)\textsuperscript{10} was employed here. Using this process resulted in the test to be highly reliable and accurate, therefore, providing confidence that the results are not due to a lack of test consistency or accuracy.

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

Significant differences in IPD were found between nonathletes (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\textsuperscript{11,15}. Stereo perception is important in 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\textsuperscript{18,25,26} identified that athletes have greater stereo acuity than non-athletes and after reviewing results from this study one possible
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248 explanation may be due to IPD. These findings may lead to future research investigating
249 whether young athletes who have a wider IPD experience more success in sport due to
250 enhanced stereo acuity. IPD is not fully developed until 19 years old in males and 14 years old
251 in females, therefore it is important that those involved in working with athletes
252 (ophthalmologists, optometrists, coaches, and parents) be aware that this may affect
253 performance. The results of this study also suggest that for adult professional baseball players,
254 IPD may be one factor in elite levels performance.
255
256 Past research was inconsistent in determining nonathlete gender differences in PD. The
257 results of this study found that male and female nonathletes were not significantly different from
258 one another in post hoc testing. These results are consistent with Hashemian et al., (2012) who found no significant difference in PD between gender. Interestingly however, results of this
259 study also found significant differences between nonathletes and MLB pupil size. A smaller PD
260 size has been shown to improve image quality as it limits diffraction as well as depth of focus.
261 Both, image quality and depth of focus, are very important attributes when playing baseball.
262 Past research has shown expert baseball players often look for rotation at the elbow and hand
263 placement on the pitcher and look to visually track a ball, including the rotation of the ball
264 detected via looking at the seams, when batting. Placement of the hand and rotation of a ball
265 on a ball at 60 feet 6 inches away may be affected by image quality. The ability to track a ball at
266 95 miles per hour with rapid changes in depth is clearly related to depth of focus. The results of
267 this study reveal that a significantly smaller PD for MLB players compared to nonathletes may
268 be a factor in their success.
269
269 Future studies should consider ethnicity as a variable in examining IPD and PD in
270 athletes and nonathletes. Not making a link between IPD, PD, and performance statistics within
271 the baseball group is a limitation of this study. Future studies should examine if those within the
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MLB group differ from one another on IPD and PD and if 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 nonathletes (males and females). Past research has shown 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 their follow-on visual skills are only one possible part of overall performance. However, when the blink of an eye can affect the ability to see a ball in baseball seemingly small differences in biological make up, like IPD and PD may provide another component in a long equation that determines success.

References


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Figure 1: RightEye set up
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Figure 2: Stimuli
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![Pupillary Distance Diagram]

**Figure 3: RightEye IPD/PD report**
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### Table 1. Descriptive Statistics for IPD and PD

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>Minimum</th>
<th>Maximum</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>227</td>
<td>61.54</td>
<td>2.66</td>
<td>0.18</td>
<td>61.19</td>
<td>61.88</td>
<td>54.00</td>
<td>66.32</td>
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<td>64.32</td>
<td>1.50</td>
<td>0.11</td>
<td>64.11</td>
<td>64.54</td>
<td>59.03</td>
<td>68.74</td>
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<td>69.91</td>
<td>2.38</td>
<td>0.20</td>
<td>69.52</td>
<td>70.29</td>
<td>66.10</td>
<td>74.97</td>
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<td>565</td>
<td>64.68</td>
<td>4.04</td>
<td>0.17</td>
<td>64.34</td>
<td>65.01</td>
<td>54.00</td>
<td>74.97</td>
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<td></td>
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<tr>
<td>Female Nonathletes</td>
<td>29</td>
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<td>0.27</td>
<td>0.05</td>
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<td>0.05</td>
<td>3.46</td>
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<td>4.12</td>
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<td>3.09</td>
<td>0.29</td>
<td>0.02</td>
<td>3.05</td>
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<td>3.25</td>
<td>2.08</td>
<td>4.12</td>
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Table 2. ANOVA Tables for IPD and PD

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<th>F</th>
<th>Sig.</th>
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<td>6337.22</td>
<td>2</td>
<td>3168.61</td>
<td>621.50</td>
<td>0.001</td>
</tr>
<tr>
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<td>2865.26</td>
<td>562</td>
<td>5.10</td>
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<tr>
<td>Total</td>
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<td>564</td>
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<td><strong>PD</strong></td>
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<tr>
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<tr>
<td>Total</td>
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<td>256</td>
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### Table 3. Post Hoc Tests for IPD and PD

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<td>0.0005</td>
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<td>-7.81</td>
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<td>0.22</td>
<td>0.0005</td>
<td>2.26</td>
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<td>0.25</td>
<td>0.0005</td>
<td>-6.16</td>
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<td>0.24</td>
<td>0.0005</td>
<td>7.81</td>
<td>8.93</td>
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<tr>
<td>Dunnett T3 Male Nonathletes</td>
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<td>0.21</td>
<td>0.0005</td>
<td>-3.28</td>
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<td>0.0005</td>
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<td>0.06</td>
<td>0.0005</td>
<td>-0.35</td>
<td>0.61</td>
</tr>
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<td>MLB Players Female Nonathletes</td>
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</tr>
</tbody>
</table>

* The mean difference is significant at the 0.05 level.
IPD comparing MLB to non-athletes

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.