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ORIGINAL ARTICLE

The Refractive Error of Professional Baseball Players

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ABSTRACT
Purpose. High levels of visual acuity are required to hit a baseball effectively. Research has shown that any decrease in vision is likely caused by low-order optical aberrations. This study is designed to validate the SVOne autorefractor, and describe the amount and type, of low-order optical aberrations present in a large cohort of professional baseball players.
Methods. A retrospective chart review on the 608 Major League Baseball players evaluated during the 2016 Spring Training Season was performed. Results for a subset of players who had both manifest refraction as well as autorefraction were calculated. Subsequently, after determining the accuracy of the autorefraction system in this population, refractive results for the entire population were determined.
Results. There was a borderline statistically significant difference in mean spherical refractive error (M) between the manifest refraction and the SVOne auto refraction (−0.273D in the manifest refraction method vs. −0.503D in the SVOne method, $P = .06$) in the subset of athletes who underwent both tests. Additionally, there was no difference in the J_0 or J_{45} cylindrical component vectors for each method. For the entire eligible population, the SVOne autorefraction system found a mean spherical refractive error (M) of −0.228D, a J_0 value of −0.013D, and a J_{45} value of −0.040D.
Conclusions. These data suggest that the SVOne autorefraction system is generally able to measure the refractive error in the baseball population. The system was slightly biased, often reporting more myopia in myopic subjects. Thus, careful evaluation of the refractive status of these athletes coupled with careful subjective refractive correction for those with less than average vision for baseball is strongly suggested.
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Key Words: refractive error, baseball, autorefraction, SVOne, sports performance

Hitting a pitched baseball has been described as one of the most difficult tasks in all of sports. The baseball, barely 3 inches in diameter, is thrown at speeds approaching 100 mph from a distance of 60 feet 6 inches. The batter must predict, based upon the initial trajectory of the ball as well as the ball's spin, where and when it will cross the plate allowing for him to strike it with a wooden bat a mere 2.75 inches in diameter. It is not difficult to understand the challenge as well as the excellent visual function required for success. In fact, baseball is one of the rare times in life when you are considered highly skilled for being successful only 30% of the time.

Previous research has described the visual function of professional baseball players as well as athletes in other sports. In professional baseball, the average visual acuity has been reported as approximately 20/12.[1] Typically, normal vision for the general population is considered 20/20[2] and the best vision humanly possible has been considered to be 20/8. The visual ability of professional baseball players is thus significantly better than the average person and in many cases has been found to approach the 20/8 limit of human vision. Clear vision seems to be important in identifying the pitched ball and making optimal contact for the best chance to gain a hit.

Errors in the refractive status of the eyes will decrease visual acuity and are likely to negatively interfere with the hitting task. Although not the only determinant of visual acuity (e.g. lens opacification, macular disorders, etc. can also affect visual acuity), the presence of refractive errors (either of the low-order or high-order varieties) certainly can result in degraded vision. In an earlier publication,[3] we described the optical aberrations present in professional baseball players. In that report consisting of 316 eyes of 162 players, we noted that professional baseball players had a low-level, and clinically insignificant, amount of the high-order aberration, trefoil, as compared to the control population. Additionally, we noted that the largest aberration was spherical

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aberration. This report concluded that the visual system of professional baseball players seemed to be a low-order optical aberration limited system with only minor, nonsignificant, amounts of high-order aberrations present.

Understanding the refractive error of these athletes is an important component in evaluating the visual function of a batter. Several studies, over the past several years, have described the importance of vision in batting success. Mann et al.[4] describe the role of visual blur (potentially a result of refractive error) on the performance of perceptual tasks. They note that perceptual tasks rely on visual information whereas motor tasks are more resistant to blur. In fact, they further note that blurred vision may have a greater asymmetric effect on the ventral visual pathway compared to the dorsal, more motor-associated visual pathway. Additionally, Mann, Abernathy, and Farrow[5] noted that the effect of blur on an interceptive skill, such as batting, was increased with increasing target velocity.

Similarly, Baron and Westheimer[6] found that visual acuity increased as exposure duration increased up to durations of 400 ms, after which duration did not affect visual acuity, whereas Adrian[7] noted that visual acuity increased with longer exposure durations up to 1000 ms. Additionally, he noted that visual acuity increased with increased target contrast. Hagee[8] noted that subjects were able to correctly identify the baseball seam spin pattern 52% of the time when viewing the baseball for an unlimited amount of time and only 38% of the time when viewing for a limited time (286 ms, $P = .015$).

Finally, Shank and Haywood[9] described the differences in fixation patterns during pitch delivery in expert and novice baseball batters. In their study, they noted that experts anticipated the pitcher's release point and moved fixation to that point, keeping fixation at that point for 150 ms after the release of the pitch. Novice batters were much more erratic in their fixation patterns and fixed on other locations than the release point such as the pitcher's head. Thus, an emerging body of literature supporting the importance of visual function (blur, contrast, exposure duration, and fixation pattern, among others not discussed here) on batting success is developing. This report describes the refractive errors of expert batters as it potentially relates to blur, one of the factors related to successful batting.

Over the past several years, we have noted an explosion in the number of commercially available systems used to detect refractive errors. In addition to the standard "autorefractors," technology ranging from systems that track the movement of the eye to systems that use wavefront aberrations have become prevalent. Several reports comparing these systems to each other, as well as to the gold-standard clinical refraction, have also been published.[10–12] In most cases, these automatic refractive error detecting systems have been found to be fairly accurate, and repeatable, when compared to clinical refraction.

Recently, a new system came to market that is portable, allows for easy transmission of results (via the iPhone base upon which it is built), is relatively inexpensive, and most importantly is reliable. A recent report comparing the results of the SVOne (Smart Vision Labs, New York, NY), an aberrometry-based autorefractor, in 50 visually normal young adults who underwent retinoscopy, subjective refraction as well as evaluation with two other commercially available autorefractors (Topcon KR-1W and Righton Retinomax-3) found that the SVOne results were not significantly different than the other subjective and objective measures of refractive error in their cohort.[13]

Refractive errors are composed of low-order optical aberrations (sphere and cylinder) as well as several high-order optical aberrations. Having previously observed that the professional baseball player's visual system is a low-order optical aberration limited system, we were curious to understand exactly what types of low-order optical aberration refractive errors were present, if any, in this population. With the advent of the SVOne, which is a reliable, data-centric, and highly portable system, we applied this technology to a moderately large cohort of professional baseball players to determine what type and magnitude low-order optical aberrations might be present in the professional baseball population. Our hypothesis, based on the previous research noted above, is that the SVOne will be able to reliably assess the refractive status of this elite population.

METHODS

After the conclusion of the 2016 Major League Baseball (MLB) Spring Training season, we retrospectively evaluated the screening and examination records of the professional baseball players we evaluated. We screened a total of 608 MLB players (both minor and major league levels), from five teams, during the 2016 spring training season. All MLB players were males. Of the 608 players screened, 557 had autorefraction performed (51 players did not complete autorefraction because of their not presenting for autorefraction or not being able to complete the test). Players who had refractive surgery (25) or players who were wearing contact lenses at the time of their screening (116) were not considered eligible for analysis. Additionally, three (3) players were not entered properly into the autorefraction database and could not be identified, and thus included, in the analysis. Thus, a total of 413 players were deemed eligible for inclusion in the study.

Screening took place in a dedicated room at each team's spring training facility. Screening consisted of a brief ocular history followed by autorefraction using the SmartVision SVOne system, other tests of vision (OptimEYEs), hand-eye coordination and reaction time (SVT) as well as visual concentration and multiple object tracking (Neurotracker) were also performed. A company representative performed the examinations to ensure that the instrument was being used according to the manufacturer's recommendations. Additionally, the operator (who was fluent in English and Spanish to ensure understanding of the instructions) was masked to any other clinical data, as the autorefraction was the first clinical measurement taken on each player. When a player was deemed to have significantly less than the published[1] average vision for a professional baseball player, he was called back, on a different day, for additional testing and evaluation. On several occasions, a manifest refraction was part of that re-evaluation. Of the 199 players who were called back for re-evaluation, further evaluation, and possible treatment, 38 required a manifest refraction.

The protocol followed the tenets of the Declaration of Helsinki, and the protocol was approved by the institutional review boards of the State University of New York College of Optometry and the Southern California College of Optometry at Marshall B. Ketchum University. The manifest refractions were conducted by the authors.

TABLE 1.

Descriptive statistics as well as *t*-test results comparing right eye data of subjects who had both autorefraction and manifest refraction performed

	M	J_0	J_{45}
Manifest refraction			
Mean	−0.273	0.0625	−0.0616
SD	0.430	0.402	0.238
Min	−0.875	−0.606	−0.434
Max	1.38	1.11	0.748
SVOne refraction			
Mean	−0.503	0.0270	−0.0529
SD	0.751	0.517	0.249
Min	−2.25	−1.11	−0.476
Max	0.875	1.33	0.832
Two-tailed *t*-test (*P* value)	0.0638	0.492	0.768

Statistical Analysis

To aggregate the refractive results from all subjects, refractive measurements were transformed into power vector components (M, J_0, and J_{45}) according to the technique of Thibos et al.[14,15] M represents the magnitude of the spherical component of the refraction, J_0 represents a Jackson Cross Cylinder (JCC) with horizontal and vertical principal meridians, and J_{45} represents a JCC with oblique principal meridians. Statistical analysis (*t*-test and Pearson correlation) was performed using Minitab Express (MiniTab Inc., State College, PA) and Microsoft Excel (Microsoft Corporation, Redmond, WA) software.

Two different analyses were performed with the autorefraction data. The first analysis compared the autorefraction data with the manifest refraction results of the 38 subjects who had both manifest refraction as well as autorefraction performed. The goal of this analysis was to compare the accuracy of the autorefraction to the gold-standard manifest refraction, as had been previously published.[13] This retrospective chart review did not allow a pre-data collection sample size determination. There were a total of 38 players who clinically required a manifest refraction after visual acuity testing, thus allowing comparison of their results to the autorefraction results. With this sample size of 38, the power of the paired sample *t*-test to detect as significant an absolute mean difference of 0.25D on the M vector component is about 0.47. A sample size of 80 subjects would be required to obtain a power of 0.80. Additionally, in an effort to minimize bias, and because of the inherent correlation in refractive status of the right and left eyes of any given subject, only right eye results are included in this portion of the analysis.

The second analysis was designed to establish the average spherical, as well as cylindrical, refractive error of the entire population of 413 eligible subjects from five MLB teams who were evaluated.

RESULTS

Part 1

Review of these data indicated that of the 38 subjects who had both manifest refractions as well as autorefraction with the SVOne device, 74% (28/38 eyes) were found to have myopic M values on manifest

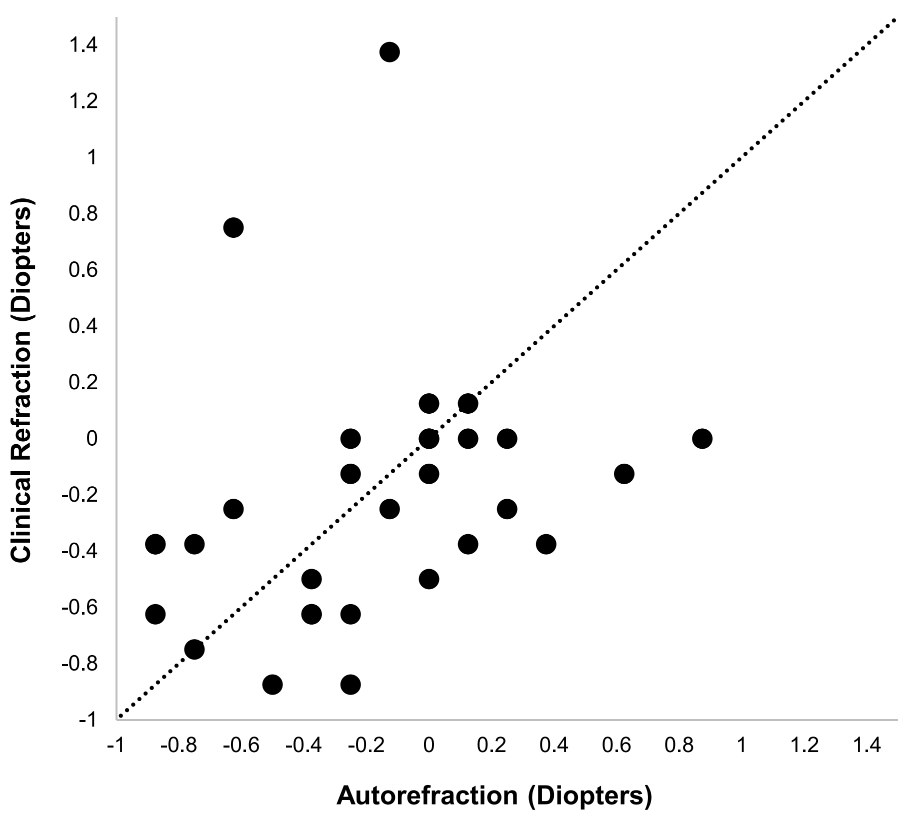

FIGURE 1.

Scatter plot and equality line of M-vector component of refractive error (manifest refraction data plotted on the *y*-axis and SVOne refraction data plotted on the *x*-axis).

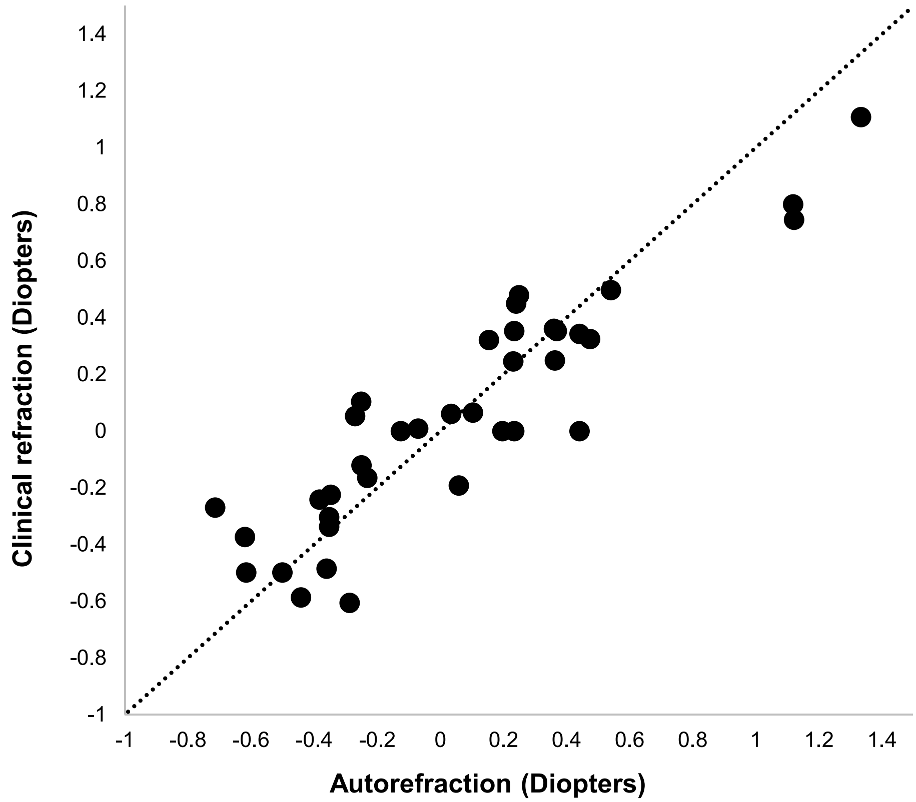

FIGURE 2.

Scatter plot and equality line of J_0-vector component of refractive error (manifest refraction data plotted on the *y*-axis and SVOne refraction data plotted on the *x*-axis).

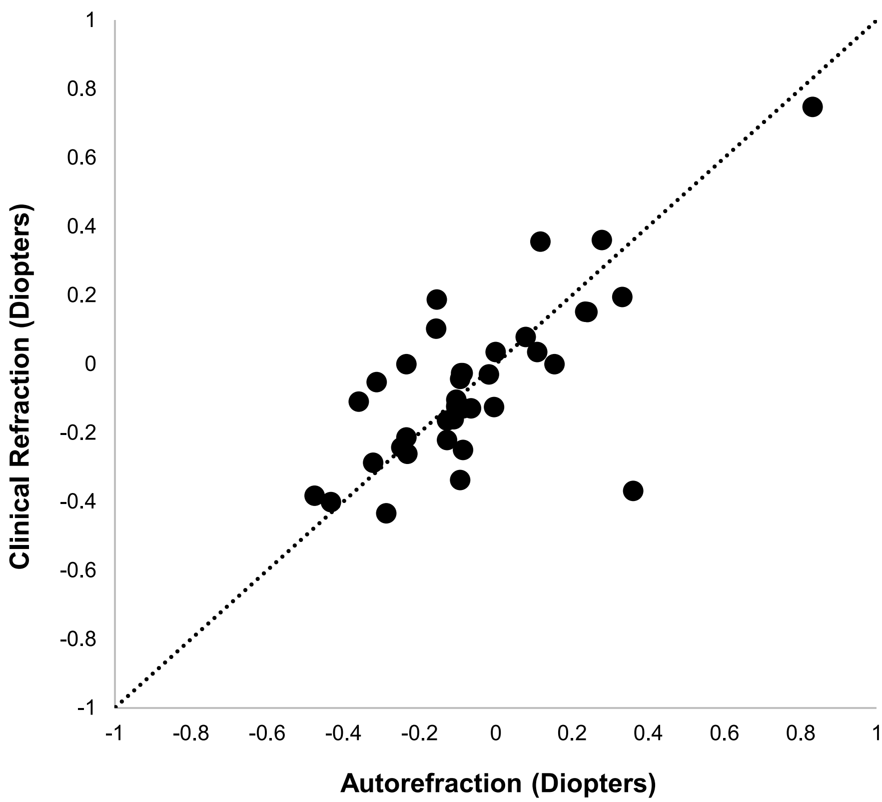

FIGURE 3.

Scatter plot and equality line of J_{45}-vector component of refractive error (manifest refraction data plotted on the *y*-axis and SVOne refraction data plotted on the *x*-axis).

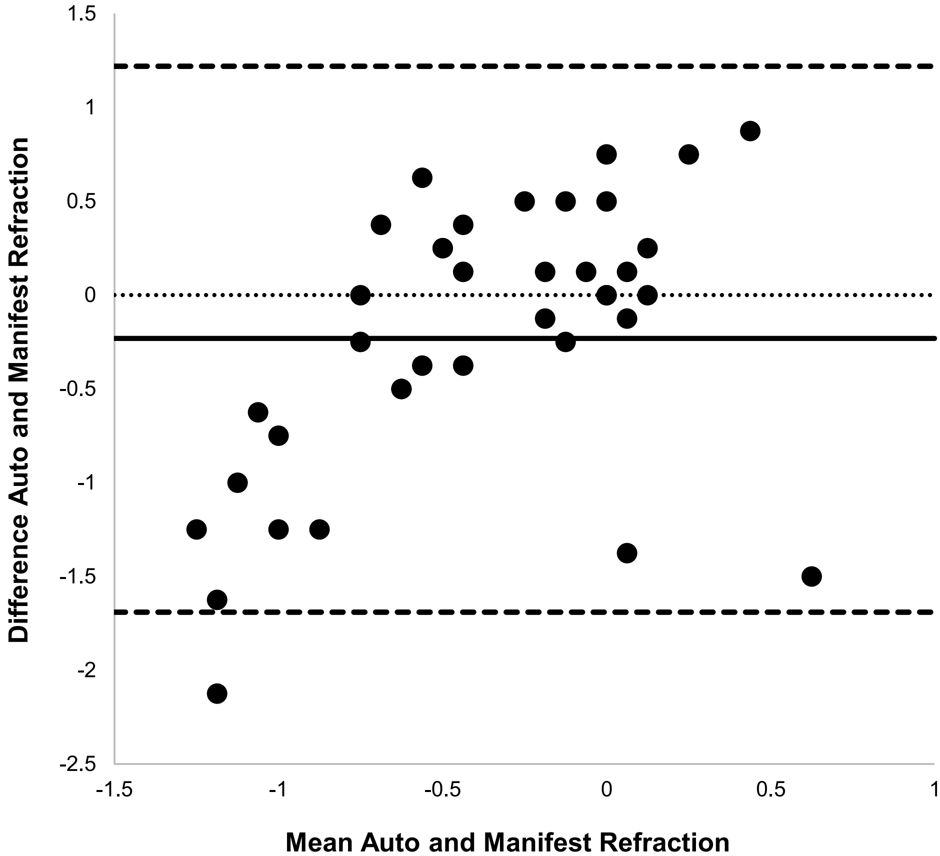

FIGURE 4.
Bland-Altman analysis for the M component of the manifest refraction and autorefraction data.

refraction whereas 66% (25/38 eyes) were found to be myopic on autorefraction. Sixteen percent (6/38 eyes) had no spherical (M) component to their refractive error on manifest refraction whereas 13% (5/38 eyes) had no spherical (M) component to their refractive error on autorefraction. Eleven percent (4/38 eyes) were found to have hyperopic M values on manifest refraction whereas 21% (8/38 eyes) were found to be hyperopic on autorefraction.

In terms of the J_0 vector component, 42% (16/38 eyes) had minus power associated with the J_0 vector component on manifest refraction, whereas 47% (18/38 eyes) had minus power associated with the J_0 vector on autorefraction. Only 5% (2/38 eyes) had no power associated with the J_0 vector component on manifest refraction whereas none of the 38 players had no power associated with the J_0 on autorefraction. Interestingly, 53% (20/38 eyes) in each group had plus power associated with the J_0 vector component when comparing the manifest refraction to the SVOne results.

In regards to the J_{45} vector component, 66% (25/38 eyes) were identified as having minus power associated with the J_{45} vector component on manifest refraction whereas 71% (27/38 eyes) had minus power associated with the J_{45} vector component on autorefraction. Five percent (2/38 eyes) had no power associated with the J_{45} vector component on manifest refraction, whereas none of the SVOne refractions had no power associated with the J_{45} vector. Twenty-nine percent (11/38 eyes) of both groups had plus power associated with the J_{45} vector.

The mean and standard deviation for each group (manifest and SVOne) as well as each component vector for the right eye data is presented in Table 1. Of note is that the mean spherical refractive error in the manifest group is −0.273D whereas in the SVOne group it is −0.503. This difference was close to the 95% certainty level for statistical significance (P = .0638). The remaining component vectors, J_0 and J_{45}, were not statistically significantly different (P = .492 and 0.768, respectively). In addition, the mean magnitude of the component vectors was subclinical in each case, ranging from +0.06 to −0.06D of astigmatism.

Lastly, Pearson correlation coefficients were determined for each vector between the manifest refraction result and the SVOne result. The M vector component (sphere) showed a correlation of 0.306 (P = .0620), whereas the J_0 and J_{45} vector components were much more correlated with r = 0.792 ($P < .0001$) and r = 0.728 ($P < .0001$), respectively.

Figs. 1, 2, and 3 graphically demonstrate these data, as well as the equality line for each refractive component. Additionally, a Bland-Altman difference plot was created for each refractive vector (Figs. 4, 5, and 6) to detect any bias, or skew, in the results. Review of Fig. 4 demonstrates a fixed bias of approximately −0.23D, with the SVOne providing more myopic results than the manifest refraction for the M vector component. Additionally, it seems that a proportional bias is present in that the SVOne measures a greater amount of myopia, the more myopic a subject is in comparison to the gold-standard manifest refraction. Of note is that the fixed bias is minimal and barely of clinical significance.

Evaluation of the Bland-Altman plots for the J_0 and J_{45} vector components (Figs. 5 and 6) demonstrates a small fixed bias,

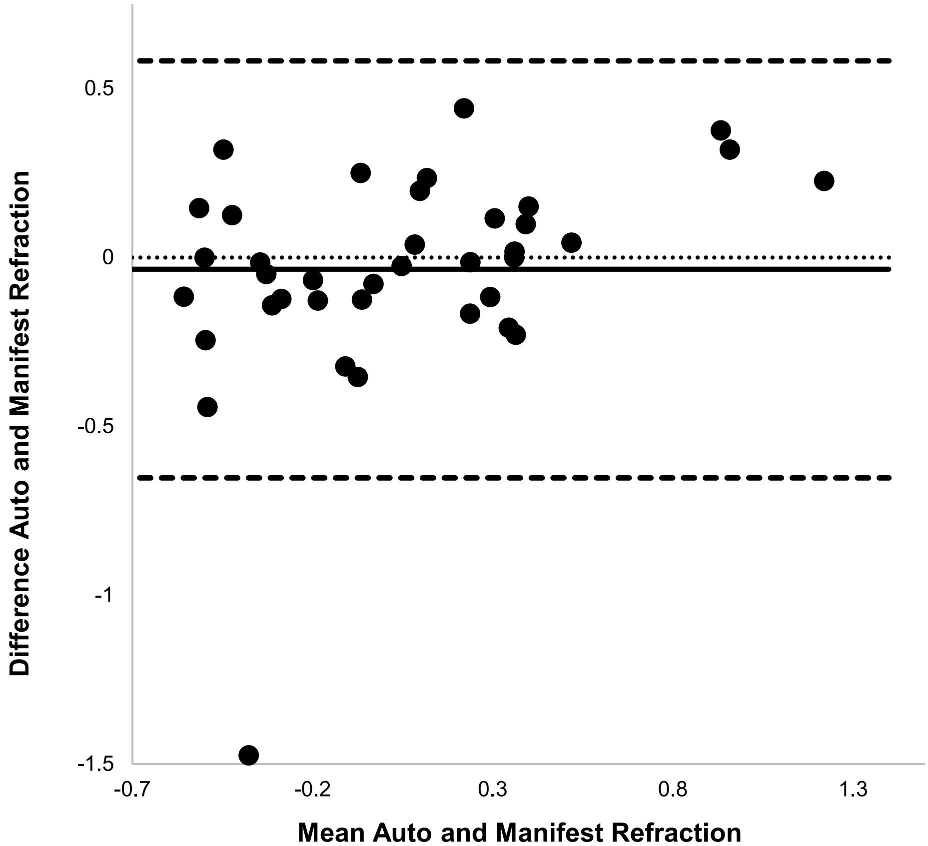

FIGURE 5.
Bland-Altman analysis for the J_0 component of the manifest refraction and autorefraction data.

−0.04 and 0.009, respectively, both well within clinical ranges of tolerance. There does not seem to be any proportional bias in either component vector present.

After reviewing the above data, tables, and figures, we concluded that our results were in agreement with the previously published data; there was no clinically significant difference between the SVOne data and the manifest refraction data for these subjects and that the SVOne data was an accurate measure of refractive error in the baseball population. Therefore, we continued to evaluate the entire cohort's SVOne data to determine the statistical characteristics of the refractive error for the MLB baseball population tested.

Part 2

Review of the results for the entire eligible set of subjects (413) revealed the following in the spherical (M) vector: myopia in 439 of the 826 eyes (53%), no spherical component to their refractive error in 75 of the 826 eyes (9%), and hyperopia in 312 of the 826 eyes (38%) tested. In the J_0 vector, there was minus power in 421 of the 826 eyes (51%), no power (i.e. within ±0.12D of zero) in 49 of the 826 (6%), and plus power in 356 of the 826 eyes (43%) tested. Finally, in the J_{45} vector component, there was minus power in 368 of the 826 eyes (44%), no power in 54 of the 826 eyes (7%), and plus power in 404 of the 826 eyes (49%) tested.

Table 2 documents the average refractive error in each component vector for each eye of the entire cohort of MLB subjects. The mean spherical refractive error was −0.192D of myopia in the right eye and −0.264D of myopia in the left eye, whereas the mean cylindrical refractive error in both the J_0 and J_{45} vector components was very small and nonclinically significant ranging from −0.05454 to +0.00270D in magnitude. Additionally, histograms were created (Figs. 7, 8, and 9) for each vector component, of each eye, to graphically document the incidence of refractive error.

To compare the data for the right and left eyes, a two-tailed *t*-test was used to analyze the right eye results and the left eye results in all three power vectors. In all groups, except for the J_{45} vector component, there was no statistically significant difference between the right and left eye measurements. In the J_{45} group, a statistically significant difference was found, but the interocular difference (−0.03D for the right eye and −0.05D for the left eye) was found to be less than a 0.25D difference and thus was deemed to be nonclinically significant.

DISCUSSION

These results demonstrate several important findings important to the care of professional baseball players. Firstly, the results show that the SVOne autorefraction system can measure the small, but important, refractive errors in this population, although a slight bias toward increased myopia was noted (0.237D). This population differs from those of other reports describing non-athletes. Athletes are clinically felt to have either no refractive error or only a very small refractive error, which makes them different than the general population and thus the impetus for validating the device

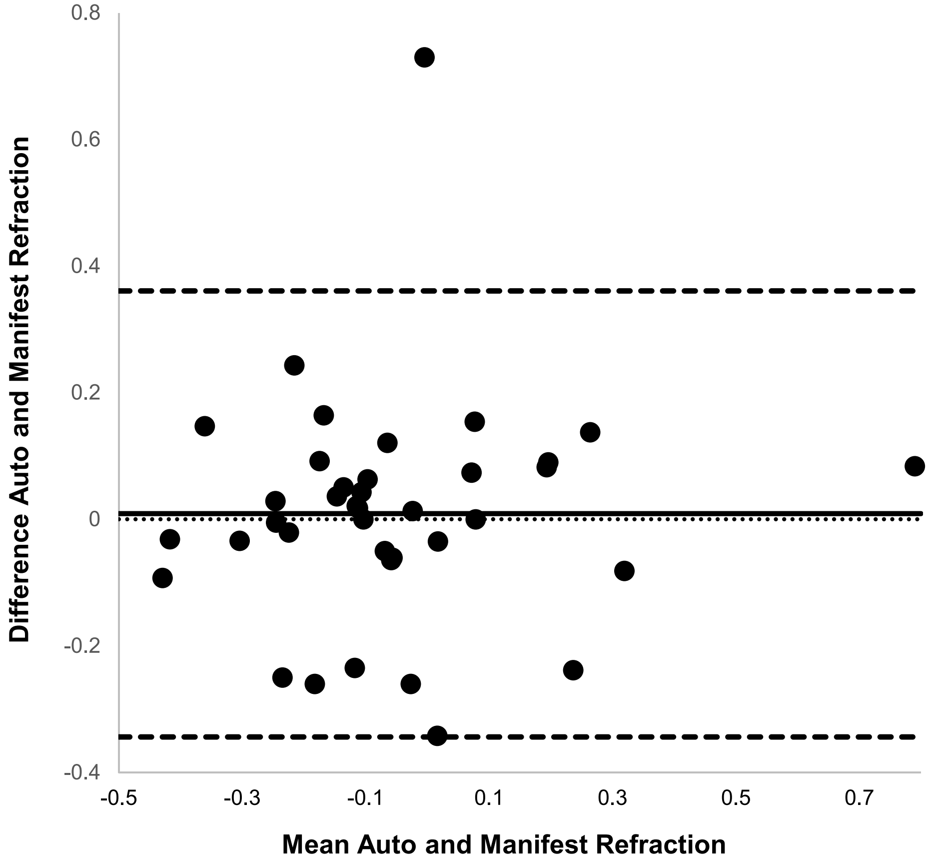

FIGURE 6.

Bland-Altman analysis for the J_{45} component of the manifest refraction and autorefraction data.

in this population. Fortunately, the SVOne was able to accurately determine the presence of any refractive error. There was less than a quarter diopter difference between the manifest refraction and the refraction determined by the SVOne system, suggesting that the SVOne system was able to detect refractive error in this population and provided accurate results.

Secondly, the magnitude of the refractive error detected by autorefraction in the entire baseball cohort suggests that, on average, there may be a very small spherical refractive error present in this population and essentially no astigmatic refractive error. This is important as even a very small refractive error should be explored for possible correction if an athlete is to obtain the vision required to perform optimally in their sport. Specifically, in baseball, previous research[1] has determined an average visual acuity of approximately 20/12 in the MLB baseball population. Even a small refractive error, left uncorrected, could decrease vision to the 20/20 level or worse, which is likely insufficient to allow optimal batting performance. Additionally, the impact of any refractive error, if present, on their visual function is often greater than what is seen in the average population with a similar refractive error (authors' clinical experience).

When reviewing the results of this study, one should consider the fact that wearers of contact lenses as well as athletes who had previously undergone refractive surgical procedures were excluded from analysis. This, although necessary, as evaluation of either group would likely have created spurious results, may have led to an underestimation of the refractive error in the entire baseball population, although in light of the number excluded as compared to the overall number of included athletes, this shift would have likely been minimal.

It is interesting to compare the incidence of myopia and astigmatism in this cohort of MLB athletes to the corresponding rates in the general population. Vitale et al., in a 2008 report,[16] presented refractive information on 14,213 subjects aged 20 years or older. This report found that myopia of less than or equal to 1D was present at a rate of about 33% in 20–39-year-old American males, with myopia less than or equal to 0.5D found at a rate of 47% in the

TABLE 2.

Descriptive statistics as well as *t*-test results, for each eye, of all MLB subjects who underwent autorefraction

	M	J_0	J_{45}
Right eye			
Mean	−0.192	−0.0293	−0.0258
SD	0.712	0.284	0.188
Min	−3.00	−1.11	0.772
Max	2.62	1.33	0.832
Left eye			
Mean	−0.264	0.00270	−0.0545
SD	0.830	0.343	0.222
Min	−6.12	−1.00	−1.18
Max	2.12	3.62	1.12
Two-tailed *t*-test (*P* value)	0.0955	0.0576	0.0249

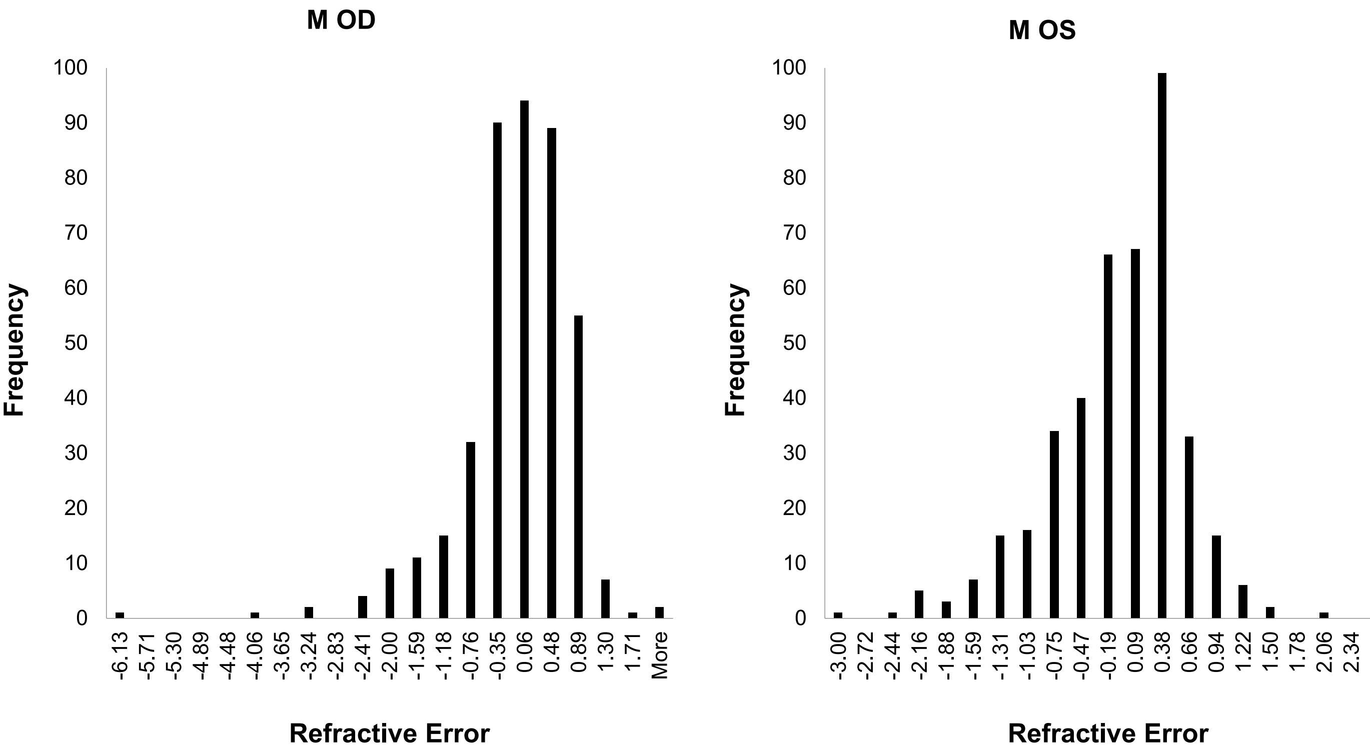

FIGURE 7.

Histogram of M-vector component for each eye of 413 professional baseball players.

same age group. Hyperopia equal to or greater than 3D was noted at 1.3% in males between 20 and 39 years of age. Astigmatism (≥1D) was found at a rate of 24.1% in the 20–39-year-old male population. In our cohort, myopia was found to be present in 53% of athletes (439 out of 826 eyes), and hyperopia was found to be present in 38% of athletes (312 out of 826 eyes). Our cohort seems to have a greater rate of myopia than noted in the 2008 report, although the magnitude of the myopia was likely smaller. Similarly, our cohort had a hyperopic rate of 38%, whereas the 2004 report notes only 1.3% in the 20–39-year-old age group. As in the case of myopia above, the

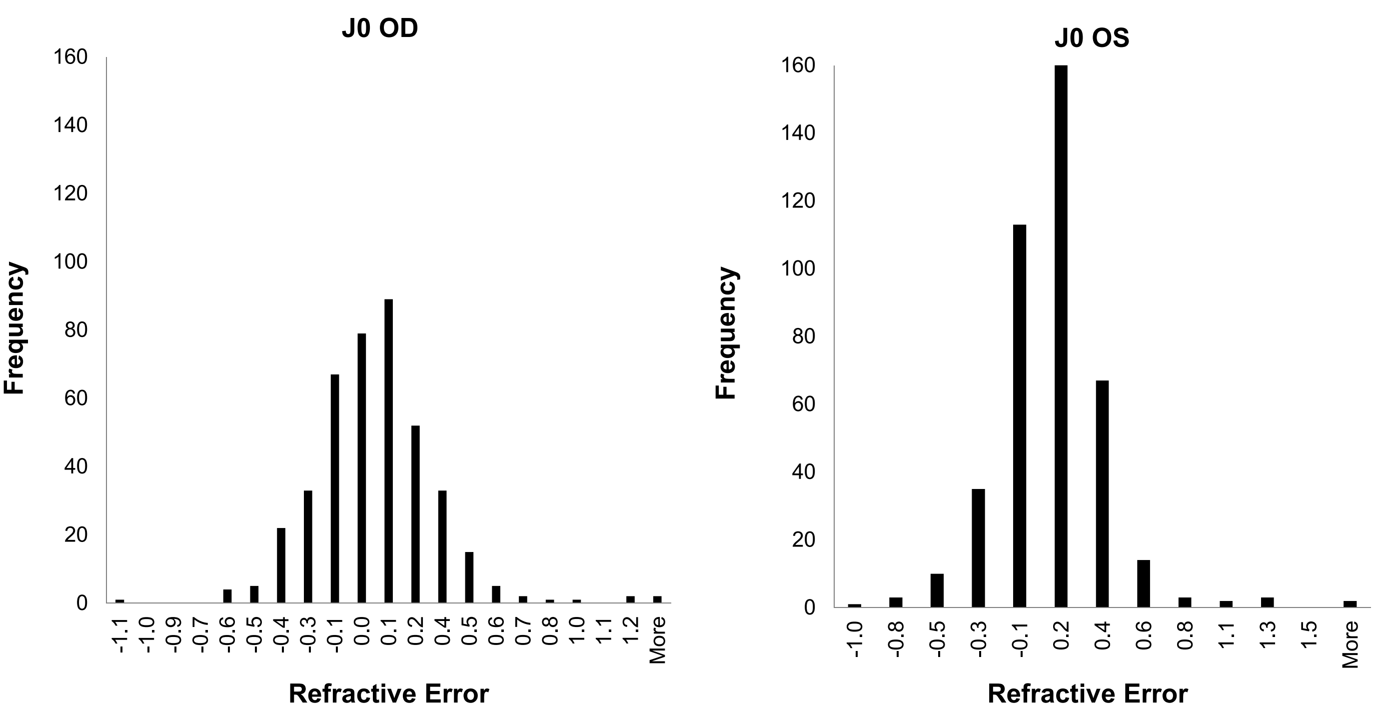

FIGURE 8.

Histogram of J_0-vector component for each eye of 413 professional baseball players.

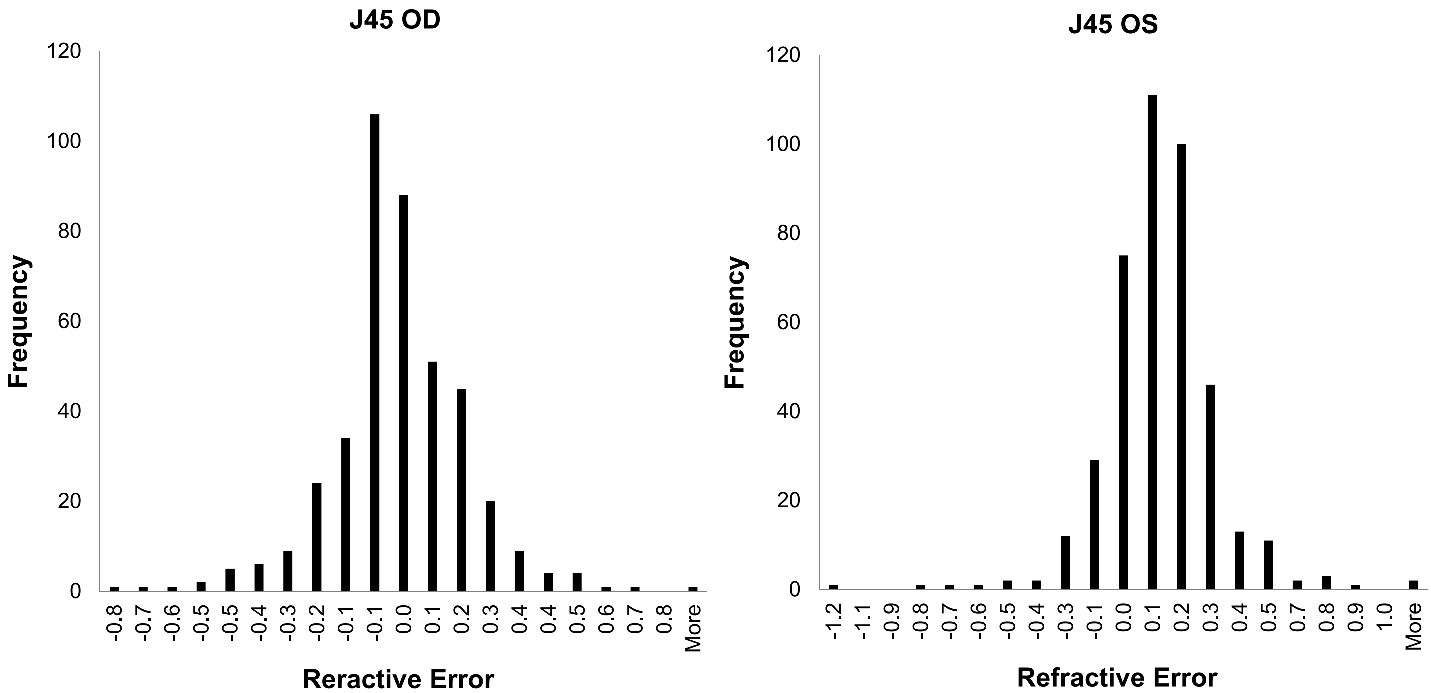

FIGURE 9.

Histogram of J_{45}-vector component for each eye of 413 professional baseball players.

2008 report only includes subjects with 3D of hyperopia or greater, whereas our cohort frequently had much less hyperopia. Vitale et al. does note that approximately 35% of the population studied (males and females) had refractive errors between +0.5 and −0.5D. Unfortunately, the 2008 report does not further break down the refractive error rates by absolute amount of refractive error—making comparison to our cohort more challenging.

Williams et al.,[17] in a 2015 report, describe a meta-analysis of 15 population studies conducted between 1990 and 2013 by the European Eye Epidemiology Consortium. In their results, presented in 5-year age intervals, they note an incidence of myopia (<0.75D) of 40.9% in males aged 25–39 years. Additionally, they note a rate of hyperopia (>1D) in the same population of 6.81% and astigmatism of any amount at a rate of 16.5% in the included males. Our data shows a higher rate of refractive error than the above noted reports, although this may be partly caused by different age ranges as well as different refractive error cut-offs. Alternatively, the results may reflect a possible increased incidence of myopia in the recent past.

Regardless of the minimal differences between the manifest refraction group and the autorefraction group, which was of borderline significance in sphere (M) and not clinically significant in cylinder (J_0 and J_{45}) and considering the bias of the SVOne autorefraction system, often reporting more myopia in myopic subjects, we do not feel that autorefraction can replace manifest refraction in this group, at this time. Specifically, if we consider the results of Pearson correlation, we note in terms of astigmatism good correlation, but only moderate correlation between individual spherical results ($r = 0.306$). Therefore, on an individual basis, the autorefraction was only *moderately* correlated with the manifest refraction. Instead, we suggest that autorefraction be used in conjunction with other measures of visual function, as an adjunctive screening method, to aid in the determination of which athlete requires additional, in-depth, ocular evaluation.

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