Pacific University
CommonKnowledge

College of Optometry

Theses, Dissertations and Capstone Projects

11-2004

The effect of phoria and fixation disparity on the hitting placement of baseball players

David Beisiegel
Pacific University

Alan Copeland
Pacific University

The effect of phoria and fixation disparity on the hitting placement of baseball players

Abstract

Twenty players from Pacific University's baseball team were tested on the Pacific Sports Vision Performance Profile (PSVPP) to determine if phoria and fixation disparity, as measured by the PSVPP, correlates to actual hitting tendencies. PSVPP results indicate that a statistically significant correlation exists between actual batting placement and phorias indicated by the PSVPP (pe0.001). Those exophoric players who bat right handed tend to hit to left field, orthophores tend to hit to centerfield, and esophores tend to hit to right field. The reverse is true for left and right field placement for left handed hitters. Furthermore, a trend was also noted in the phorias and fixation disparities of starters ('first string' players) vs. non-starters in that the starter's values were found to be closer to orthophoric. This suggests that as one moves up the ranks in baseball, those athletes who perform the best may be likely to have or develop a low or zero phoria and fixation disparity. It also points to the possibility that hitting placement may be affected by phoria compensation using prism.

Degree Type

Thesis

Degree Name

Master of Science in Vision Science

Committee Chair

Alan Reichow

Subject Categories

Optometry

The Effect of Phoria and Fixation Disparity on the Hitting Placement of Baseball Players

David Beisiegel

And

Alan Copeland

Contributors:

Matthew Grange

And

Darin Johnson

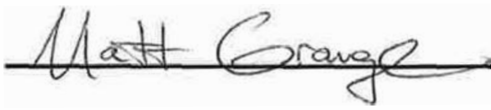
A thesis submitted to the faculty of the
Pacific University College of Optometry
Forest Grove, OR
for the degree of
Doctor of Optometry
November, 2004

Advisor:

Alan Reichow, OD

Signatures

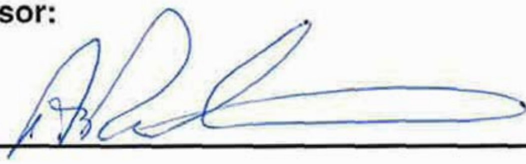
Contributing Authors:



Matthew Grange

Darin Johnson

Advisor:



Alan Reichow, OD

Abstract

Twenty players from Pacific University's baseball team were tested on the Pacific Sports Vision Performance Profile (PSVPP) to determine if phoria and fixation disparity, as measured by the PSVPP, correlates to actual hitting tendencies. PSVPP results indicate that a statistically significant correlation exists between actual batting placement and phorias indicated by the PSVPP ($p<0.001$). Those exophoric players who bat right handed tend to hit to left field, orthophores tend to hit to centerfield, and esophores tend to hit to right field. The reverse is true for left and right field placement for left handed hitters. Furthermore, a trend was also noted in the phorias and fixation disparities of starters ('first string' players) vs. non-starters in that the starter's values were found to be closer to orthophoric. This suggests that as one moves up the ranks in baseball, those athletes who perform the best may be likely to have or develop a low or zero phoria and fixation disparity. It also points to the possibility that hitting placement may be affected by phoria compensation using prism.

Introduction

Baseball is a very appealing sport for visual scientists because of its extremely high visual demands. Consider that a small sphere traveling at nearly 100 miles per hour must be hit precisely with a small bat. Some maintain that hitting a baseball is the most difficult visual task required of any athlete [1,2,3,4]. Fortunately, from a statistical research perspective batting averages and pitcher's earned run averages provide very tangible and readily available measures of athletic performance. Baseball is a sport in which dynamic visual skills play as significant a part, if not more so, than any other sport. As a consequence, many research studies and screening prospects involve baseball players [5, 6]. Yet to date there has been little research devoted towards investigating the effects of phoria and fixation disparity on hitting placement of baseball players. It is the author's intent that the findings from this study may provide information to ultimately increase baseball players hitting placement performance.

Proper anticipation of baseball speed and trajectory, along with the tracking of the target as it comes toward the batter, are agreed to be two of the most important factors in the hitting process [7]. Additionally, anticipation timing, which refers to the player's estimation of the time the stimulus arrives at the proper response location must be accounted for. Garofalo, Drotzmann, and Gable found that anticipation, as indicated by performance on the Bassin Anticipation

Timer, had no statistically significant correlation on hitting [8]. Dunham and Reeve conducted a study that indicated that baseball players were no more accurate than non-players in the estimation of a baseball's arrival at the front edge of home plate [9].

Dunham and Reeve also examined the effects of gender and eye preference on the anticipation of coincidence [10]. This methodology again involved subject estimates of a baseball's arrival at home plate. Their studies showed that no significant difference exists for gender or eye preference. It is noteworthy that in a related study, Dunham and Reid showed that on tasks requiring coincidence-anticipation, a significant difference exists between males and females in adults and pre-pubescent children [11]. The study attributed the differences to sociocultural and physiological factors rather than an inherent gender difference.

This leaves visual posture and tracking as the most likely deciding factor on how the brain perceives when a ball arrives at a specific point in space. Phoria measurements indicate the amount of over or under-convergence the eyes experience when examining an object at a particular plane of regard in space. Maddox stated that if all innervation to the ocular muscles were to cease, the eyes anatomical position of rest would be one of considerable divergence.He described tonic convergence as being responsible for moving the eyes from the position of anatomical rest to a more convergent position [12]. This latter position is described as the physiological position of rest, or the phoria position, and is the position taken by the eyes when no stimuli to fusion are present. Deficient tonic convergence would result in exophoria, whereas excessive tonic convergence would result in esophoria. Orthophoria is the term used to describe the condition where the eyes are aligned so that both are centered exactly on the target. This is supported by Erenfeldt who investigated studies of the Pulfrich phenomenon, which found that the early part of a baseball's flight is the primary information used to anticipate the arrival of the ball to the batter. The timing of impulses conducted from the eyes appears to be critical for precise localization of objects by either the motion-in-depth (baseball hitting) or sideways-motion (Pulfrich phenomenon) channels [13].

Early experiments into eye movements suggested that most observers were unlikely to clearly track or follow moving objects traveling at velocities above 50 degrees per second or 25mph [14]. Using cinematography, Hubbard and Seng determined that a pitched baseball cannot be followed during its final 8-15 feet of flight [15] and using a similar technique, Mowen determined that it was not possible to track a tennis ball for the 0.05-0.20 seconds prior to contact with the racquet [16]. This is likely due to the inadequacy of pursuit eye movement with the speed of the target. Pursuits are relatively slow eye movements and if the target is moving rapidly this results in the inability to keep up, which needs to be corrected by a catch-up saccade. Saccades are short, rapid and jerky eye movements used to catch up with a rapidly moving proximal object[1']. Vision during saccades is reduced due to a compensating mechanism known as saccadic suppression.

Thus considering that pursuit and saccadic eye movements limits one's ability to accurately track a high speed object at a close range, phorias at distance were determined to be a more relevant measurement in baseball rather than those at near.

Clear vision is also inhibited when the player and the ball are both in motion [20]. Thus, the visual system is unable to follow and process a moving object clearly unless the gaze velocity or the combined conjugate speed of head and eye movements are able to stabilize the retinal image on the foveae. Motion therefore inhibits vision but the ability to track a moving object, particularly when the player is also moving, is obviously a considerable advantage for participants in dynamic sports [21]. Hale also recorded the average visual reaction time of major league baseball players to be 0.24 seconds, during which a 90 mph pitched ball can travel 26 feet [18]. In order to contact the ball, the hitter must anticipate its position during its flight half way between the pitcher and the home plate. According to McCrone, top class batters do not necessarily have quicker reaction times than the general population but have learned from experience how to anticipate the position of the ball in the final 200 milliseconds during which it cannot be seen. A spinning or swerving delivery often eludes the receiver by the last minute change of direction but top class batters will respond by developing a repertoire of compensating strokes such as a hook or late cut [19].

Swing initiation is of primary importance, and visual posture under batting situations can dramatically change the perception of where the ball is. An over convergent esophore would localize the ball as being closer to them while an under-convergent exophore would initiate their swing later due to localization of the ball being further away [17]. This could be seen as another example of the SILO effect where an exophore (as simulated with base-in prism) perceives the target as being smaller or further away in space [22]. Ono found a high positive correlation (r=0.95) between the magnitude of apparent speed and the extent of eso/exo phoria obtained. This shows that the more esophoria a player displays, the earlier they will react to a baseball arriving over home plate (and vice versa for exophoria) [23].

A phoria is an indication of how a person visually represents their current view of the world at that moment in time [24]. It is recognized that there are shifts in this internal representation of reality both inward and outward, all of which may occur simultaneously in different fields of gaze. While most people tend towards a certain type of characteristic shift, the norm is a high degree of variability. Why then would one consider measuring a phoria or compensating a person with a phoria? Phorias come in several different varieties. The phoria that is measured in the analytical examination is done under "disassociated" conditions. Note: The person's eyes are still pointed together and the person's eyes do not somehow miraculously become disassociated from each other like some reptiles. The word disassociated is derived from the fact that when a vertical prism is placed before one eye the person, on a phenomenological basis, reports seeing two distinct separate images of the object before them. The fact that most people see these two separate images is what leads to the term disassociated, not the persons eyes, which still point together at whichever of the two images the person chooses. Dr. Robert Kraskin labels this test a measurement of a monocular phoria [24]. When the person fixates with the right eye, he looks directly at that object in space as if that view of the object were the only object present. Therefore, Kraskin considers the response of the person here to be a total person response. Since the person being tested is a binocular individual the response of the person is the response of a binocular person. According to Kraskin, under conditions of disassociation, the person responds to one image or the other just as they would under binocular conditions. When the person concentrates on the image before the left eye, he is looking at that object in space as if that was all that was being seen and he does so binocularly as a whole person. Kraskin coined the terms for these tests as right and left phorias. He recognized that in the condition of anisometropia (different spherical refractive conditions in each eye; ex. -3.00 OD – 1.00 OS), the right and the left phorias may be very different.

An additional type of phoria was developed and refined over the past 25 years or so and has been called either an associated phoria, a fixation disparity (FD) or a binocular phoria [12]. The concept of FD is that the person should view a scene binocularly where the entire scene except for two small parts is viewed through both eyes simultaneously. To measure a horizontal FD two vertical arrows or straight lines or makers are placed in the center of the scene. On the physical measuring card the two markers are aligned directly, one above the other. Each of the arrows or markers is visible to only one eye, while being filtered and blocked from view to the other. Most methods use Polaroid filters, but anaglyphic filters can also be used. The end result is that within a binocular scene two "indicators" are masked so one image is visible to one eye only. This test is a subtle test of suppression. If one of the markers is missing, then the person is not responding to the possible information available from that area of space using that channel of input. One notices varying degrees of misalignment of the markers in some people. Since the majority of the scene is binocular, the degree of misalignment is generally much less than that measured from a monocular phoria.

Optometrists record the presence of alignment or misalignment and the direction as part of the exam. Changes in these findings over time are noted in response to the optometric treatment program administered, which may or may not include prisms. If the optometrist decides prism may be indicated, it is common to probe any misalignment with probe prisms. A series of probe prisms are placed in front of the eyes one at a time. At first, each prism usually results in images jumping to a new position. Over a few seconds the scene usually stabilizes, with the markers in a new alignment. A curve can be plotted relating the relative position of the markers under different probe lenses. This is also known as fixation disparity curve. In most people there is a range of prism lenses through which the markers remain aligned. With prism powers just outside of that range there is a slight misalignment of the markers. With more prism power, the misalignment increases and finally, when the prism powers are strong enough, the person may report frank diplopia. The shape of these curves varies for each person and can be influenced by visual training and lens treatment programs.

Methods

Subjects were 20 males, varsity level baseball players at Pacific University. They ranged in age from 18 to 23 years of age. All completed the Pacific Sports Vision Performance Profile (PSVPP), and were examined during times of practice as well as in game situations to determine their hitting tendencies.

The Pacific Sports Vision Performance Profile (PSVPP) is a test that was designed to screen for deficits in visual performance in scenarios that typify the cognitive and neuromuscular demands of sport[25]. Subjects are first questioned as to any deficits or critical feedback they are aware of concerning their sport performance. Then, vision is assessed though a battery of standardized tests that evaluate oculomotor and visual functioning. Finally, sport related demands such as visual memory, dynamic visual acuity, cognitively loaded visual-physical tasks, and many others were tested. While all values obtained on each player's PSVPP were examined, of principle interest were the phoria and fixation disparity measures. Each subject was taken through the PSVPP protocol in an order from subjective to objective testing; from passive to more physically active tests.

The players were examined in a variety of hitting situations such as indoor and outdoor practices along with a balanced number of home and away games. A disproportionate amount of data was collected for starting vs. non-starting players, but practice data helped make the totals more comparable. One subject's data was excluded due to injury.

Each non-fouled hit that the player made was plotted on a baseball diamond diagram which was divided into three 30 degree zones labeled "left field", "center field" and "right field". At the end of the season, all of the hits made by an individual player were grouped together on a master sheet to examine for clustering of results to a generalized area. These results were then assigned values according to location, and statistically analyzed for their relationship to the phoria and fixation disparity values found for that person.

Subjects had minimal contact with the experimenters except for the PSVPP sessions at the beginning of the experiment do gather their personal data. An effort was made not to go to consecutive games, or sit in an area where we would be noticed in order to minimize the confounding variable of player-testing awareness.

Results

No instructions were given on how, when, or where to hit the balls, and no efforts were made to control pitching consistency. To this end, all variables were randomized.

Once divided up into left, center, and right field placement, the results were tabulated for individual players and then grouped together into starters and non-starters. The results for left and right field were exchanged for those players using a left-handed batting style. Results were also separated into practice vs. non-practice situations. Finally, all results were grouped together to examine consistency for the group as a whole in all testing situations.

A chi-squared statistical analysis was performed for each group in practice, each group in game situations, both groups in practice, both groups in game situations, and all players in all situations. Finally, a chi-squared test was also done for the group examining fixation disparity as a possible variable.

No qualitative analysis was performed on the individual hits of players, except to exclude foul balls. Of primary importance was the vector of the ball's departure from the bat. No accounting was taken for fly balls, ground balls, or home runs; except to note the primary direction of the ball.

Table 1: Phoria vs. Hit Location Analysis

Phoria vs. Hitting Tendency

Pacific Universitv Boxers

	Starters- Game Situations			Starters- Practice Situations			Other Players- Practice Situations		
Phora	Left Field	Cente r Field	Right Field	Left Field	Center Field	Right Field	Left Field	Center Field	Right Field
Eso	19 n=3	19 n=3	19 n=3	26 n=3	36 n=3	16 n=3	30 n=5	25 n=5	18 n=5
Ortho	13 n=3	28 n=3	35 n=3	32 n=3	25 n=3	58 n=3	7 n=l	8 n=l	6 n=l
Exo	47 n=5	49 n=5	33 n=5	67 n=5	70 n=5	67 n=5	23 n=2	15 n=2	7 n=2

	All Players - Practice Situations			All Players- All Situations		
Phoria	Left Field	Center Field	Right Field	Left Field	Center Field	Right Field
Eso	56 n=8	61 n=8	34 n=8	75	80	53
Ortho	39 n=4	33 n=4	64 n=4	52	61	99
Exo	90 n=7	**85** n=7	74 n=7	**137**	134	107

Legend

n – number of players that his specified number of balls to the specified field location

eso – esophoric

ortho – orthophoric

exo- exophoric

Table 2: Fixation Disparity vs. Hit Location

	All Players, All Situations		
Fixation Disparity	Left Field	Center Field	Right Field
Eso	10	15	9
Ortho	97	97	211
Exo	57	62	39

*Note: More of the non-starters were shown to have measurable fixation disparity (68%) vs. starters (18%)

Legend:

eso – esophoric

ortho – orthophoric

exo- exophoric

Statistical Analysis

Chi squared analysis indicates a statistically significant correlation exists between fixation disparity and ball placement to a level of probability less than .1% - X^2 (4)=40.09 ($p<0.001$). Chi squared analysis further indicates a statistically significant correlation exists between phoria and ball placement to a level of probability less than 0.1% - X^2 (4)=27.82 ($p<0.001$) for all players in all situations, all players in practice situations, and starters examined alone in practice situations. A statistically significant correlation also exists when examining only starters in game situations to a level of probability less than 2.5% - X^2 (4)=12.44 ($p<0.025$). No statistical significance was found for non-starting players in practice situations.

Conclusions

The results in this study suggest that phoria directly influences perception of where the baseball is in space and therefore when it is hit and the direction of travel. Those exophoric players who bat right handed tend to hit to left field, orthophores ten to hit to centerfield, and esophores tend to hit to right field. The reverse was found true for left and right field placement for left handed hitters.

Chi squared analysis indicates a statistically significant correlation exists between fixation disparity and ball placement to a level of probability less than 0.1% - X^2 (4)=40.09 ($p<0.001$). Chi squared analysis further indicated a statistically significant correlation exists between phoria and ball placement to a level of probability less than 0.1% - X^2 (4)=27.82 ($p<0.001$) for all players in all situations all players in practice situations, and starters examined alone in practice situations. A statistically significant correlation also exists when examining only starters in game situations to a level of probability less than 2.5%

- $X^2(4)=12.44$ ($p<0.025$). These all illustrate a strong connection between hitting tendency and resting posture of the eyes.

Furthermore, a trend was also noted in the phorias and fixation disparities of starters ('first string' players) vs. non-starters in that starter's values were found to be closer to orthophoric. This suggests that as one moves up the ranks in baseball, those athletes who perform the best are likely to have or develop a low or zero phoria and fixation disparity.

No statistical significance was found for non-starting players in practice situations. This is most likely due to the fact that there was only about 10-20% of the data available for this analysis as compared to the other findings. Given the trend of showing more of an effect with less experience in baseball, it could be hypothesized that these players would show an even greater effect if the quantity of data had been as significant as it was for the starting players.

Discussion

The results suggest that as one moves up the ranks in baseball, those athletes who perform the best are likely to have or develop a low or zero phoria and fixation disparity. It is noteworthy that many aspects of visual performance have been shown to be increased in elite athletes.

Teig used a tachistoscope flash device, which displayed increasing span-number sequences and baseball pitching sequences, to measure visual concentration at the speed of 1/100th of a second on a screening of 275 baseball players [26]. He then compared the results of the tachistoscope visual concentration test of 35 players with the highest batting averages with those for the lowest 35. Based on his method of evaluating the concentration test, he stated the better hitters overwhelmingly showed more proficiency in their ability to concentrate. He also reported that pitchers with lower earned run averages had better concentration scores.

The Sports Medicine and Vision Center in San Diego has offered a comprehensive sports vision program [27]. Vision screening has been one of its activities, and over 400 major league baseball players were evaluated within a four-year period. In 1984, players from the Kansas City Royals and Minnesota Twins were screened, and the aiming of the eyes and oculomotor skills were among the most significant of the visual skills tested. Focus flexibility, fusion flexibility, and eye tracking were 20-30% better among position players compared to pitchers. This is not surprising, because the use of the designated hitter in the American League precludes the pitcher from hitting where these skills are essential. Depth perception was also found to be superior in all players and seems to improve with age when comparing major league players to high school and college players.

Successful players in visually demanding sports are believed to have fast smooth pursuits, suppression of the vestibulo-ocular reflex, and from time to time employ an anticipatory saccade [12]. In addition to keen dynamic visual acuity and quick, accurate depth perception, success in fast-moving sports requires smooth and rapid vergences and accommodative facility. Visual reaction skills are better for elite athletes, as found by Classe [28]. However, reaction times and visual performance may deteriorate under adverse conditions such as stress, fatigue or poor lighting [29]. Professional baseball players have also been shown by Labbe to have excellent skills. Mean visual acuity, distance stereoacuity, and contrast sensitivity were measured to be significantly better than those in the general population [30]. This illustrates that, as you go from amateur to professional baseball players, more refined visual skills are exhibited.

It may also be the case that as you become more proficient in baseball, you also become more able to overcome any phoria-based effects on your hitting. With more experience, professional players may become more able to place the ball despite their phoria. If this is true, we would expect rookies show more of an effect.

An interesting implication of these findings is that it may be possible to compensate for a phoria to allow players to better plan for ball placement. Perhaps by overcompensating a phoria using prism, you could possibly reverse a ball placement tendency. For players earning their living in professional baseball this could signal a new approach to hitting strategy. For players newer to the game, it could help them improve their hitting in time to stay with the sport.

Traditionally, some optometrists have used fixation disparity to identify a possible compensatory prism lens. In the absence of some other easily identifiable cause for a person's asthenopia or visual discomfort, some optometrists have used the testing of the fixation disparity to reveal the possible need for a compensatory prism lens to remediate the symptoms. In those cases where a fixation disparity was measured and symptoms were present, the minimum prism to bring about alignment was prescribed. Clinically, this prism seems to be accepted well by most patients and does lead to the decrease of related symptoms most of the time [24]. There is little evidence that this use of prism will lead to not needing prism in the future. The patient may embed the prism into his view of the world, and the underlying condition that led to the development of the fixation disparity in the first place may once again surface in the redevelopment of a similar situation over time. This might require additional prism, and is termed prism adaptation. Use of prisms in this manner is termed "compensatory." However, the underlying causal problem is not being addressed and the prism may be embedded, leading to a new round of adaptations [31]. In most people, the prism will not embed, and it may be used to compensate the phoria to a more orthophoric posture and exophores could perhaps be induced with prism to place the ball similar to an esophore and vice versa. Theoretically, spectacle or contact lens prism prescriptions could be used to aid in ball placement.

Traditionally, phorias have been looked at as being more of a musculature of neurological over- or under- contraction or stimulation. Terms such as tonic vergence, fusional vergence and proximal vergence were hypothesized as explanations of the resultant phorias. All one had to do was determine what part of the phoria each of these vergences contributed to determine which was too strong or which was too weak. The concept was that the phoria was a sum total of the physiological and musculature misalignment of the eyes under non-fused conditions. Through the conventional concepts of accommodative convergences/accommodation (AC/A) relationships it was recognized that when certain amounts of sphere powers were placed in front of the person, there were changes in the phoria measures[32]. Therefore, in some situations plus for near in the presence of a measured esophoria was deemed to be more desirable than prescribing base out prism for the person to compensate for the esophoria. The opposite was not generally true, although one can certainly find those who have over-minused a person with a measured exophoria at near (using excess minus or less plus). An interesting dilemma if that on the one hand, it appears that alignment is critical, but in the other hand, the expected findings for the phorias, which are part of the Optometric Extension Program's 21-point vision analysis, are not orthophoria (that condition where no eso or exo deviations are noted). At distance the expected phoria is 0.5 prism diopters of exophoria and at near is 6 prism diopters of exophoria [24].

Each type of eye movement is normally tested clinically as a separate entity while the head is kept stationary. This approach is understandable as it facilitates analysis and repeatability. However, it fails to simulate the true situation in many sports where a combination of several types of eye and head movements is required either to follow or avoid a moving target. The peripheral retina is sensitive to movement and initiates corrective eye movements so that the central retina, where the visual acuity is best, views the object of interest. Two separate mechanisms, each with separate pathways to specific areas of the brain, are believed to control eye movements. The focal system is concerned with central vision and conscious object identification, while the ambient system is more reflexive, peripheral and concerned with controlling fine movement [33].

Also of interest is the fact that of the 275 major league ball players -individuals who were very successful athletically- 21% had never had an eye examination and another 25.7% had not had one in over 5 years [26]. Yet, by the time a player reaches the major leagues, hundreds of thousand of dollars have been spent for minor league seasoning, training camps, coaching and attempts to develop baseball skills. In most cases, these resources have been expended based on the assumption that the player's vision is normal without making any effort to find out otherwise. To this day, vision remains a largely neglected area of sport performance evaluation.

References

1. Bard C and Fleury M. Age, Stimulus Velocity and Tack Complexity as Determiners of Coincident Timing Behavior. *Journal of Human Movement Studies* 1985;11: 305-317.

2. Bootsma RJ and Oudejans RRD. Visual Information About Time-to-Collision Between Two Objects. *Journal of Experimental Psychology: Human Perception and Performance* 1990:16(1): 21-29.

3. Sports Vision Section, American Optometric Association. *Sports Vision Guidebook: Baseball.* St. Louis, MO: 1993.

4. Gregg JR. *Vision and Sports, An Introduction.* Stoneham, MA: Butterworth Publishers. 1987.

5. Egan D. Visual actors in Hitting and Catching. *Sports Science* 1997;15(6): 533-558.

6. Laby DM, et al. The Visual Function of Professional Baseball Players. *American Journal of Ophthalmology* 1996;122(4): 476-485.

7. Beitel PA and Hardy CJ. Stimulus Velocity and Movement Distance as Determiners of Movement Velocity and Coincident Timing Accuracy. *Human Factors* 1982;24(5): 599-608.

8. Garofalo R and Drotzmann DA, Gabel D. Anticipation of Coincidence in Baseball Players. Optometric thesis, Pacific University College of Optometry, Forest Grove, OR: 1989.

9. Dunham Jr P. Coincidence-Anticipation Performance of Adolescent Baseball Players and Non-Players. *Perceptual and Motor Skills* 1989;68: 1151-1156.

10. Dunham Jr P and Reeve J. Sex, Eye Preference and Speed of Stimulus Effect on Anticipation of Coincidence. *Perceptual and Motor Skills* 1990;71:1171-1176.

11. Dunham Jr P and Reid D. Information Processing: Effect of Stimulus Speed Variation on Coincidence Anticipation of Children. *Journal of Human Movement Studies* 1987;13: 151-156.

12. Grosvenor T. *Primary Care Optometry, Anomalies of Refraction and Binocular Vision* 3rd ed. Newton, MA: Butterworth-Heinemann, 1996.

13. Erenfeldt AJ, Hoefle FB, Bonafed, B. Baseball Hitting, Binocular Vision and the Pulfrich Phenomenon. *Research Ophthalmology* 1996;114(12): 1490-1494.

14. Ludvigh E and Miller JM. Study of Visual Acuity During Ocular Pursuit of Moving Test Objects. *Journal of Optical Society of America* 1958;48: 799-802.

15. Hubbard AW and Seng CN. Visual Movements of Patterns. *Research Quarterty* 1954;25: 42-57.

16. Mowen S. Eye Tracking During the Tennis Forehand Volley. Masters Thesis, Texas Womens University, Denton, TX: 1976.

17. Loran DFC and MacEwan CJ. *Sports Vision.* Newton, MA: Butterworth-Heinemann, 1996.

18. Hale CJ. Vision in Sports. *Sports Vision* 1992;8: 26-29.

19. McCrone J. Shots Faster Than the Speed of Thought. *The Independent on Sunday* 1993;27 June: 71.

20. Ditchburn R and Ginsborg B. Vision With Stabilized Retinal Image. *Nature* 1952;36: 36-39.

21. Rousse MW, DeLand P, Christian R, Hawley JA. A Comparison Study of Diagnostic Visual Acuity Between Athletes and Non Athletes. *Journal of the American Optometric Association* 1988;50: 947-950.

22. Paulson D. *Procedures of Refraction, Optometry Class Manual.* Pacific University College of Optometry, Forest Grove, OR: 1997.

23. Ono H and Gonda G. Apparent Movement, Eye Movements and Phoria When Two Eyes Alternate in Viewing a Stimulus. *Perception* 1978;7(1): 75-83.

24. Optometric Extension Program. *OEP Vision Therapy- Tools of Behavioral Vision Care: Prisms.* Santa Ana, CA: 1996.

25. Coffey B and Reichow AW. Optometric Evaluation of the Elite Athlete - Pacific Sport Vision Performance Profile. *Problems in Optometry* 1990;2: 1.

26. Teig DS. *Major League Baseball Research Project.* Sportsvision West Symposium, Atlantic City, NJ: 1984.

27. Smith PB. *Visual Characteristics of Major League Baseball Players.* Sportsvision East Symposium, Las Vegas, NV: 1984.

28. Classe JG, et al. Association Between Visual Reaction Time and Batting, Fielding and Earned Run Averages Among Players of the Southern Baseball League. *Journal of the American Optometric Association* 1997;68(1): 43-49.

29. Martin WF. *Insight to Sports.* Sports Vision Inc., Seattle, WA: 1993.

30. Laby DM, et al. The Visual Function of Professional Baseball Players. *American Journal of Ophthalmology* 1996;122(4):476-485.

31. North RV, Henson DB, Smith TJ. Influence of Proximal, Accomodative and Disparity Stimuli Upon the Vergence System. *Ophthalmic Physiological Optics* 1993;13(3):239-43.

32. Hung GK. Quantitative Analysis of the Accommodative Convergence to Accommodation Ratio: Linear and Nonlinear Static Models. *Biomedical Engineering* 1997;44(4):306-316.

33. Ono H and Gonda G. Apparent Movement, Eye Movements and Phoria When Two Eyes Alternate in Viewing a Stimulus. *Perception* 1978;7(1): 75-83.

Acknowledgements

The authors would like to thank the players and coaching staff of Pacific University's baseball team for their participation in this study. We would also like to thank our advisor, Dr. Alan Reichow, for aiding in the original protocol and data analysis of this study.

Biographies

David Beisiegel and Alan Copeland are both graduates of Pacific University College of Optometry. Their efforts provide the bulk of the material presented in this thesis. They are credited with being involved with many different student activities and organizations while being students at Pacific University College of Optometry.

Matthew Grange is a fourth year student at Pacific University College of Optometry. Upon completion, Matt plans to practice optometry in Minneapolis, MN. He looks forward to providing comprehensive family eye care. Matt is very involved in the community and likes to spend time playing golf, fishing, and attending a variety of music events.

Darin Johnson is a fourth year student at Pacific University College of Optometry. Upon completion, Darin plans to practice optometry in St. Cloud, MN. His area of focus will be on low vision, while also being involved in the many aspects of general practice. Darin is a hunting, fishing and sports enthusiast, and enjoys spending time spent with his wife, Telli.