Effect of oculomotor posture on spatial judgement in golf putting

Kent S. Fronk
Pacific University
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Abstract
This investigative study was designed to determine whether or not potential errors in spatial judgement associated with oculomotor posture (fixation disparity and/or heterophoria) have a consistent effect on golf putting errors. Although fixation disparity is not a new phenomenon in optometry, little research has been devoted to its effects on visually guided motor performance. Previous studies have shown that inducing changes in heterophoria causes errors in distance judgements; this study deals only with naturally occurring fixation disparity and heterophoria. In theory, fixation disparity misalignments will cause golfers to perceive the hole in a different position than that in which it is actually located. Results showed no relationship between direction and/or magnitude of fixation disparity (or heterophoria) and putting error. A possible explanation for these results is that the subjects have learned to compensate for this perceptual error.

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EFFECT OF OCULOMOTOR POSTURE ON SPATIAL JUDGEMENT IN GOLF PUTTING

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SUBMITTED TO THE FACULTY OF PACIFIC UNIVERSITY COLLEGE OF OPTOMETRY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE: DOCTOR OF OPTOMETRY

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<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>2</td>
</tr>
<tr>
<td>Abstract</td>
<td>3</td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>Method</td>
<td>9</td>
</tr>
<tr>
<td>Experimental Procedure</td>
<td>12</td>
</tr>
<tr>
<td>Results</td>
<td>14</td>
</tr>
<tr>
<td>Discussion</td>
<td>16</td>
</tr>
<tr>
<td>Conclusion</td>
<td>18</td>
</tr>
<tr>
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<td>19</td>
</tr>
<tr>
<td>Figures and Tables</td>
<td>22</td>
</tr>
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ABSTRACT

This investigative study was designed to determine whether or not potential errors in spatial judgement associated with oculomotor posture (fixation disparity and/or heterophoria) have a consistent effect on golf putting errors. Although fixation disparity is not a new phenomenon in optometry, little research has been devoted to its effects on visually guided motor performance. Previous studies have shown that inducing changes in heterophoria causes errors in distance judgements; this study deals only with naturally occurring fixation disparity and heterophoria. In theory, fixation disparity misalignments will cause golfers to perceive the hole in a different position than that in which it is actually located. Results showed no relationship between direction and/or magnitude of fixation disparity (or heterophoria) and putting error. A possible explanation for these results is that the subjects have learned to compensate for this perceptual error.
INTRODUCTION

Fixation disparity is a small misalignment of the primary lines of sight of the two eyes occurring during fusion. This condition is tolerated without diplopia as long as the misalignment does not exceed Panum's fusional area, an area in which retinal images are fused even though they fall on noncorresponding areas of the retina. The present study investigates the hypothesis that spatial judgment errors may be attributable to fixation disparity; i.e., that the misalignment of the foveolae will cause perception of an object in a different position than it is actually located. The apparent position of the object is at the point of intersection of the primary lines of sight. This concept can be shown diagrammatically as follows:

--------------------------------------------
Insert Figure 1
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Hypothetical Errors: right eso-short left right exo-long right
left eso-short right left exo-long left
OU eso-short OU exo-long

Several studies have discussed and experimentally shown changes in perceived distance and direction, although with a theoretical basis not specifically related to fixation disparity. Most often these changes in perception were associated with direction and magnitude of induced
heterophorias. It is pertinent to note that inducing a phoria also typically induces fixation disparity in the opposite direction, i.e. inducing esophoria simultaneously induces exo fixation disparity and inducing exophoria simultaneously induces eso fixation disparity (Schor, 1979a; Ogle, 1967). This study will investigate spatial judgement errors hypothetically associated with naturally occurring fixation disparities and habitual heterophorias. Since these conditions are habitual and assuming they are not of recent onset, it is likely that perceptual adjustment and/or compensation has been made to correct for the predicted spatial errors.

Ebenholtz and Wolfson (1975) reported a series of experiments which showed shifts in apparent distance after sustained fixation of an inducing stimulus across a series of symmetrical convergence positions between 10 centimeters and 2 meters. Convergence was stimulated and varied using a mirror stereoscope. They found variations in perceived distance depending upon the distance of the inducing stimulus. These variations fit a linear function in which the near convergence positions (induced esophoria, exo fixation disparity) produced shifts toward greater perceived distance, and far convergence distances (induced exophoria, eso fixation disparity) produced shifts toward a lesser perceived distance. This is contrary to the popular clinical belief that exophoria is related to increased perceived distance and esophoria is related to decreased perceived distance.

The authors have used a muscle potentiation theory as explanation for these changes in perceived distance due to sustained convergence. Muscle potentiation refers to an involuntary component of continued innervation in the direction of previous muscle stimulation. Since the increased muscle tension
is involuntary, subconscious registration of eye-position information based on the monitoring of voluntary motor signals should be in error to the degree that the potentiation effect must be overcome (Ebenholtz and Wolfson, 1975). For example, there would be an increased voluntary innervation to diverge in compensation to induced esophoria (exo fixation disparity). Conversely, there would be an increased voluntary innervation to converge in compensation to induced exophoria (eso fixation disparity). Thus, changes in perceived distance should occur whenever the eyes have been maintained predominantly in near or far convergence positions. Again, in the case where the fixation disparity and phoria are naturally occurring, no changes in innervational patterns are expected since it is probable that the subject has already compensated perceptually.

Subsequent studies (Paap and Ebenholtz, 1976, 1977) confirmed the findings on distance after effects (greater and lesser with induced esophoria and exophoria, respectively) using wedge prisms rather than a mirror stereoscope to manipulate the inducing convergence positions. Prolonged fixation of a near target has also been found to induce effects similar to those induced by convergent (base-out) prisms (Ebenholtz, 1981; Shebilske, et al. 1983).

Schor (1979a, 1979b, 1980) has found that the magnitude of induced fixation disparity with prisms decreases as the duration of binocular fixation increases, thus indicating an adaptation to the prism. This is consistent with previous work of Ogle and Prangen (1953), Mitchell and Ellerbrock (1955), Carter (1965), and Ogle (1967). The decrease in fixation disparity is explained by fast and slow fusional vergence mechanisms. The fast mechanism aligns the eye in response to retinal image disparity, the slow mechanism sustains binocular alignment and is believed to be stimulated by the output, or effort, of
the fast mechanism. The prism adaptation is a manifestation of slow fusional vergence processes. The fast fusional vergence mechanism appears to refer to a phenomenon similar to Ebenholtz's concept of voluntary motor signals.

Further discussion of the muscle potentiation theory (Ebenholtz and Fisher, 1982) indicates that the direction and magnitude of the induced heterophoria is the key to innervational changes. The premise being that compensatory changes in innervational patterns, or muscle tonus, serve as distance cues to the perceptual system. The present study investigates whether the distance cues to the perceptual system are related to the simultaneously induced fixation disparities. It can also be predicted that if a naturally occurring fixation disparity is corrected to zero or ortho, spatial judgements will be in error exactly opposite to the above diagrammed predictions (Fig. 1). For example, in the case of a habitual right eso fixation disparity a short-left spatial error is indicated; however, if this eso disparity were corrected to ortho with a base-out prism the predicted spatial error would be long-right. This prediction is in fact the topic for a subsequent study.

Shebilske, et al. (1983) attempted to replicate the findings of Ebenholtz and Wolfson (1975) using more naturalistic conditions to induce esophoric shifts, (i.e., needle threading for 15 minutes) which allowed subjects to a) choose their own working distance, b) move their heads freely, and c) view in a well illuminated, structured environment. The results were confirmed and, in addition, a supplemental experiment showed more pronounced findings (larger induced esophoria and greater overestimation of distance) where phorias were induced with ten minutes of fixation on a target 11 cm. away.

Again, each of these studies showed findings consistent with the
predictions of the present hypothesis in light of the fact that base-out prism or prolonged near fixation simultaneously induce esophoria and exo fixation disparity, and base-in prism simultaneously induces exophoria and eso fixation disparity. It is important to note that this study will associate naturally occurring fixation disparity and heterophoria with spatial judgements whereas in each of the previously mentioned studies fixation disparity and heterophoria were induced. Also, the test distance for this study was six meters, previous work in this area was done primarily inside one meter.

A new method of measuring fixation disparities has been investigated (Remole 1983, 1984, 1985) based upon border enhancement. The technique is not easily applicable in a clinical setting nor for the present study since subjects must be trained extensively to properly respond to the test. Remole's results suggest that fixation disparities may be much larger than those measured with conventional methods, implying that associated spatial errors would also be larger. As in previous studies, disparities were induced using forced vergences and it was found that the border enhancement misalignment was consistently much larger than conventional fixation disparity measures, though effects were minimal when the misalignment was very small.

**METHOD**

Distance fixation disparities, distance phorias, sighting eye, and visual acuity of 17 highly skilled golfers were measured and recorded. Fixation disparities were measured with an instrument constructed by the authors since
no device is readily available for measurement of actual fixation disparities at 6 meters. Traditional devices, the AO vectograph and Mallett unit, allow only for measurement of the associated phoria. The designed instrument (Fig. 2) uses movable verticle slits, allowing for not only measurement of actual fixation disparity, but also eye-specific fixation disparity. The device is a 36 X 28 X 8 cm. metal box with internal lighting, two 5 watt incandescent bulbs. The front is translucent white plastic with acuity letters (20/40, 20/20, 20/15) on either side of a central circle which is blacked out with slits open and polarized (as later mentioned). The central circle is similar in visual angle (1.5 degrees) to the Disparometer (Sheedy, 1980) providing a peripheral fusion lock. Foveal fusion locks were omitted in order to maximize the magnitude of fixation disparity (Carter, 1964; 1980). Only the slits, 3 X 60 mm, are polarized creating a biocular situation. The specific eye is determined by centering the top slit (seen by the right eye) and taking measurements with the bottom slit (seen by the left eye) for left eye disparity, and vice versa for right eye disparity.

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Insert Figure 2

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Lateral phoria measurements were taken at six meters with an AO Ultramatic phoropter using the standard von Graefe technique (Borish, 1975). In addition to fixation disparity and phoria measurements, sighting eye was determined and visual acuity measured. A minimum of 20/20 OU was required to participate in the study. Habitual correction was worn for all testing and putting.
The subject sample was composed of 17 highly skilled golfers. Subjects were chosen for the study based upon the fact that they frequently perform a task, putting, which requires a high degree of visual perceptual alignment. Since the subjects have already attained a high level of skill at this task mechanical errors would be minimized.

The golfers were required to attempt 10 consecutive putts at each of two different cups, both located 6 meters from them but in different directions (Fig. 3). They were asked to putt the ball to stop in the center of the cup to the best of their abilities. Putting was done indoors on synthetic carpet with texture and rolling speed very similar to natural grass greens. This allowed for a very flat putting surface without some of the variations found in natural grass greens such as slope or break, the grain of the grass, footprints, ballmarks, etc. The cup was standard size (4 1/4" in diameter) and made with white chalk on the brown carpet. This was used in favor of an actual cup or indoor practice cup so that there would be no deviation of the ball on putts which would have hit or "lipped" the cup. Misses were measured in centimeters using a polar coordinate system (Fig. 3). Entrance test data and putting error data were gathered by different experimenters, thereby minimizing any chance of experimenter bias. As an incentive to maximize concentration and performance, a $50 prize was awarded to the golfer with the best results on the putting trials. The experimental data were collected during daylight hours (9am-2pm) at a local country club where the golfers had come to play practice or tournament rounds or to participate in other golf related activities.
To minimize potential compensation for spatial errors leading to missed putts, immediate feedback was eliminated by use of an occlusion device (Fig. 4) which blocked the subject's view of the ball. This device is an opaque nylon curtain mounted in a frame which can be mechanically opened or closed. When open, the subject had full view of the ball, putting path, cup and surrounding area; however, upon contact with the ball the curtain was dropped occluding all but the first 40-50 cm of the ball’s path.

EXPERIMENTAL PROCEDURE

Initially each golfer filled out a questionnaire asking name, address, handicap, dominant hand, golf hand, and if they have a tendency to miss putts in any particular direction—long, short, left, right. Testing began with visual acuity measurement at 6 meters, a minimum of 20/20 OU was required to participate in the study. Next, sighting eye was determined using a hole card, three trials were run to establish consistency. If all three were not the same a fourth was done, and if three of four were not the same the subject was considered as having no preference.

Lateral phorias were then measured at 6 meters using the von Graefe technique. The subjects were dissociated using Risley prisms in an AO Ultramatic phoroptor, 6 prism diopters (p.d.) base-up OS, 15 p.d. base-in OD. Four measures were taken starting from the base-in side and then alternately from BO, BI, BO. The phoria was considered to be the mean of these four measures using eso = +, exo = −, sign convention.

Phoria measurements were followed by measurement of fixation disparity. These measures were done in free space (no phoroptor) using the instrument (Fig. 3) described previously with polarized glasses. Each subject was given the following instructional set:
1. Does the top line appear to be in the exact center of the circle?  
   [The initial position viewed by subject was with the top line in the exact center of the circle and the  
   bottom line to the far left.]  
   - If "NO", it was centered subjectively.

2. I will be moving the bottom line from left to right. Say "NOW" when it is aligned directly below the top  
   line.  
   - Measurement #1 was taken at this position, and then the bottom vernier was moved to the far right.

3. I will now be moving the bottom line from right to left, again say "NOW" when the bottom line appears  
   to be directly below the top line.  
   - Measurement #2 was taken, and then the bottom vernier was moved to the exact center of the circle  
   and the top moved to the far left.

4. Does the bottom line appear to be in the exact center of the circle?  
   - Measurements #3 and #4 were taken in similar fashion to #1 and #2 with the subject aligning the top  
   vernier.

The verniers were moved at approximately 4-6 mm/sec for all measurements. The measurements were  
recorded as the difference between top and bottom vernier in millimeters and later converted to arc minutes.  
The magnitude of fixation disparity used for analysis was determined by averaging the 4 measurements (2  
right eye and 2 left eye) using eso = +, exo = - sign convention. The specific-eye was considered to be that  
with the greatest magnitude of disparity.

The putting trial was performed by each golfer after having been given the following instruction set:  
1. You may take a few practice puts at either or both of the cups to get the feel of the carpet [most putt  
   2 or 3 times to each cup]. Now make two puts to an imaginary point approximately halfway between  
   the two cups. (This was to eliminate immediate feedback prior to the test puts.)

2. You will be making 10 consecutive puts to each cup. Please try your best to put the ball to stop in  
   the center of the cup. There will be a $50 prize for the golfer who performs best on the putting trials.

3. You will be allowed to visually align each putt prior to striking the ball; however, upon contact this  
   occlusion device (Fig. 4) will be dropped in front of your eyes [demonstration]. Please do not peak  
   around the occlusion device to see where your ball stops.

4. After the tenth putt to cup #1, you are to again make two puts to an imaginary point between the two  
   cups without occlusion.

5. You will then make 10 more puts to cup #2, with occlusion, similar to the first ten.  
   After each put the error was measured from the center of the cup to the ball with the measuring device  
   shown in Figure 1, and recorded in centimeters and degrees.

The total time for all testing and putting trials was 20-30 minutes for each subject.
RESULTS

The findings revealed that of the 17 subjects, four had right-eye fixation disparity, nine had left-eye fixation disparity and four were considered nonspecific. Subjects fell into the latter catagory if the difference between right and left eye disparity was less than .14 arc minutes. Disparities ranged from .14-1.86 arc minutes with a mean of .582 arc minutes. The mean heterophoria was1.58 p.d. (absolute value) ranging from 2.25 p.d. esophoria to 2.75 p.d. exophoria; two subjects were orthophoric.

The putting data was categorized into one of four quadrants based upon the polar coordinate system described earlier, quadrant I=0-90 degrees, quadrant II=90-180 degrees, quadrant III=180-270 degrees, and quadrant IV=270-360 degrees. In analyzing the fixation disparity data each subject was assigned a predicted quadrant (P) based on the eye and direction of the disparity (See Table 1 for a summary of hypothetical predictions and analysis). The other three quadrants were labeled:

NP1-the quadrant correct with respect to predicted distance, but opposite the lateral prediction

NP2-the quadrant correct with respect to lateral prediction, but opposite the distance prediction

NP3-the quadrant diagonally opposite the predicted quadrant.

These data were analyzed in various ways using all of the subjects or specific subgroups of them. Chi-square analysis was used to determine if the frequency of putts to any particular quadrant was significant in all or any of the subgroups of subjects. The Student t-test was used to determine if the amount of linear error in any one quadrant was significant for all or any of the
subgroups. The statistics showed no significant relationships between frequency or linear error and fixation disparity or heterophoria in any of the analyses (p > .05).

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Insert Table 1

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The initial analysis used all of the subjects and all of their putts except those falling within +/- 5 degrees of either the x- or y-axis for frequency and linear error statistics. These data were also analyzed to determine if only predicted distance error or only predicted direction error was significant. The data were divided into two hemifields rather than four quadrants for these computations. Distance error was considered as only long or short, thus including all putts except those within +/- 5 degrees of the x-axis. Direction error was considered only left or right, eliminating those putts within +/- 5 degrees of the y-axis. Each of the conditions was analyzed to determine if frequency error (number of misses per quadrant) or linear error (total distance error per hemifield) were significant.

Similar analyses comparing direction and distance error relationships together, and then direction and distance errors individually were run on four different subgroups. The first subgroup was the six golfers with the largest magnitude of fixation disparity (greater than .43 arc minutes). Another was the five golfers with the lowest magnitude of fixation disparity (less than .29 arc minutes). The third subgroup was the six golfers with eye-specific fixation disparity the same as their sighting eye. The last was the ten golfers with the lowest handicaps (seven scratch, two with a 1 hdcp., and one with a 2
The spatial errors relative to the subjects' phorias were analyzed in a similar manner, although without any reference to direction error. For the purposes of this study it was predicted that esophoria will cause an underestimation of distance, putting short, and exophoria an overestimation, putting long. (The predicted errors for phoria were based upon commonly held clinical views, despite experimental literature to the contrary.) Chi-square analysis showed no relationship between direction of heterophoria and frequency of distance error, nor did the Student T-test show a relationship between direction of heterophoria and magnitude of linear error, p > .05 for both.

DISCUSSION

The results indicate that overall the putts fall quite randomly throughout the quadrants, without apparent relationship to fixation disparity or phoria. This randomness is somewhat expected with regard to the theory proposed previously, primarily because those with long standing fixation disparity will likely compensate for these perceptual errors over time. This is especially true in the case of a highly skilled task, such as golf putting, that has been diligently practiced for years.

In comparison to the results of previous studies concerning spatial judgement error (Ebenholtz et. al., 1975, 1981, 1982; Paap & Ebenholtz, 1976, 1977; Shebilske, 1983), no relationship was found between visually guided motor performance and direction or magnitude of heterophoria. It should again be pointed out that previous work dealt with induced heterophoria and testing
distances much less (usually less than one meter) than the present study (six meters).

Also, it is obvious from the literature that there is still a good deal of confusion concerning the relationship between magnitude or direction of fixation disparity and the related heterophorias as pointed out with citations from a pair of 1978 studies: "If fixation disparity were caused by heterophorias, or if it should even represent some form of heterophoria, one would expect a consistent relation between the magnitude and direction of the fixation disparity and the heterophoria. Clearly, such a correlation does not exist." (Palmer and von Noorden, 1978). And in complete contradiction, "A cause-effect relationship between the heterophoria and fixation disparity has been shown to be existing in the experimental situation. This experiment adds evidence to the idea that fixation disparity is the result of an inability for an individual to efficiently overcome a heterophoria." (McCullough, 1978).

There are several other factors which may have contributed to the apparent lack of relationship between predicted spatial error and fixation disparity or phoria. Most important is that the magnitudes of fixation disparity and phoria were relatively small, mean = .582 arc minutes and mean = 1.58 prism diopters, respectively. Subjects with larger magnitudes of phoria and fixation disparity were desired, but our available subject population of highly skilled golfers was very small. Secondly, experienced golfers routinely try to putt past the hole when in natural golfing conditions. This strategy may have superseded our specific instruction to try and putt the ball to stop in the center of the cup, or the attempt to break this strategy may have caused unpredictable errors. Thirdly, the test putts were done indoors, and although specific steps were
taken to make conditions as natural as possible, the environment is simply not the same. Finally, fixation disparity and heterophoria may vary with different positions of gaze. All measurements were taken in primary position of gaze, but when putting many of the golfers faced 60-90 degrees from the cup and used lateral versions when visually aligning their putt. This was allowed to keep mechanical performance as natural as possible.

Although the present study found no correlation between habitual fixation disparity and spatial judgement error, there is still a vast amount of research needed in this area before definite conclusions can be drawn.

CONCLUSION

This study compared the relationship between naturally occurring fixation disparity and spatial judgement errors in golf putting. It was hypothesized that fixation disparity will have an effect on spatial judgement depending upon the eye and magnitude of the disparity. No such relationship was found. This result was somewhat expected since the study dealt only with naturally occurring fixation disparities for which the subjects have had much time and practice in learning to compensate.

Future research will investigate the effects of compensating habitual fixation disparities and inducing fixation disparities upon visual spatial judgement at distances greater than four meters. This study and those to follow will serve to benefit sports vision practitioners in enhancing athletic performance, and will aid in the understanding of visually guided motor performance.
REFERENCES


Hypothetical error due to fixation disparity.
FIGURE 2

FIXATION DISPARITY DEVICE
Schematic of putting trials.
### TABLE 1

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Summary of hypothetical predictions and analyses.