

Is Your Eye on the Ball?: Eye Tracking Golfers while Putting

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Abstract

A research study was completed in which a portable eye-tracking system was used to monitor the locus of fixation of four golfers of various experience levels while they completed a set of putting tasks. The data obtained allow quantitative assessment of where the golfers are looking during various phases of the putting task. The objectives of this study were to determine if the player's skill level influenced their eye movements and whether any unsuspected eye movements existed. The results show many interesting trends. As expected, the putting results correlated strongly with experience level. Better results were obtained with more consistent viewing patterns, longer fixation durations (a steady gaze), and greater percentage of time viewing the hole (rather than the ball). The tools developed in this research show promise for future studies on golf performance and applications in golf instruction.

Introduction

What a golfer does with his eyes during a stroke is a topic of universal consideration among the golfing public. Golf instruction almost always includes some advice on what to look at before and during the execution of a shot. Although perhaps misguided, "keep your eye on the ball" is a mantra for many golfers and golf instructors. This work was motivated by the question of just what golfers are looking at during a stroke and whether they are looking at what they recall by introspection. Due to technical limitations of currently available eye-tracking technology, the current experiment was limited to examination of eye movements during the putting stroke.

It is not difficult to find advice on what golfers should look at during a putting stroke. Perhaps the most widely cited references on putting stroke analysis and instruction are those of Dave Pelz.^{1,2} In *Putt Like the Pros*,¹ Pelz describes the importance of a set routine and outlines his own seven step routine. In that routine, he includes specific instructions on where to look. These include step 2, look at target, step 4, move eyes from target to ball and focus on it, step 6, return eyes along target line to target, and finally step 7, look back to the ball. Thus Pelz suggests a sequence of viewing before the stroke of hole - ball - hole - ball. Pelz further explains that the pre-shot routine should be automatic noting that "you'll never see any deviation in my seven-step pre-stroke process." Clearly, Pelz has indicated that where one is looking during preparation for the putting stroke is

extremely important and that it is equally important that the procedure be consistent. In his more recent work, *Dave Pelz's Putting Bible*,² Pelz provides similar advice. He expands the pre-stroke routine described above (now referred to as the "ritual" of the stroke itself) to the full routine of lining up the putt and assuming the address position. In his five-step routine, Pelz includes specific references to where the player should be looking in each of the five steps. After those five steps, the player would finalize the address of the ball and trigger the stroke with a ritual like the seven-step procedure outlined above (although Pelz has adopted a new, shorter ritual in his later book). There is no question that golf instruction in general, and putting instruction in particular, is ripe with references about just where the player should be looking during various stages of the preparation for, and execution of, a stroke. This is one of the motivations of this research ... do golfers really look where they've been instructed to, or where they think they are?

Other recent work on eye-tracking during a sporting activity was completed by Robert Singer at the University of Florida.³ In his work, reported briefly in a 1999 press release, the eye movements of pool players were recorded during the execution of a shot. Their results suggested that more skilled players, those obtaining better results, had steadier eyes. In other words, those that fixated for the longest durations on the target were more successful at executing the shot. Singer's work suggests that similar results might be obtained for golfers during the putting stroke and thus players who spent longer times fixating on the target, or other key locations, would perform better.

Jeff Pelz and his graduate students in the *Visual Perception Laboratory*⁴ at the Rochester Institute of Technology (and no relation to Dave Pelz) have developed a portable eye-tracking system that has been used in numerous experiments to record visual behavior during normal everyday tasks.⁵ One of many interesting results from their research has been the discovery of eye movements that are made without the experimental subjects knowledge. For example, subjects asked to wash their hands in a public restroom would often look ahead to the next task while involved in another activity. They might be looking at the paper towel dispenser while turning on the faucet with no knowledge that they are looking ahead to an object in a future task. The availability of this research instrument in close proximity to a couple of avid golfers searching for an excuse to install a putting green in one of their laboratories led to the birth of this project. There was a natural curiosity to record just exactly where golfers are looking during a putting stroke and, given the above results, a question as to whether they might be gazing at various locations during the stroke without conscious knowledge. This combination of facilities, interested researchers, and interesting questions with unobvious answers led to the experiment described below.

Experimental

Putting Green

All measurements were made on an artificial putting green installed in the *Color Image Perception Laboratory* at the Rochester Institute of Technology. The putting green used was a commercially available product from PuttGolf, LLC.⁵ This putting green allows golfers to attempt putts of just over eight feet in length

across a synthetic surface into a realistic hole. The surface putts very much like a high-quality bent grass putting green. This indoor putting surface can also be adjusted in numerous ways to produce various putting contours (*e.g.*, uphill, downhill, left-to-right, right-to-left, rollovers, *etc.*). Due to limitations in the current design of the portable eye-tracking system, data must be collected indoors under lower illumination levels than typical sunlit scenes. The laboratory in which the putting green was installed includes diffuse overhead illumination that simulates natural daylight (however at energy levels typical of office illumination). In addition to the diffuse daylight illumination (like an overcast day that makes green reading difficult), a tungsten-halogen photographic studio illuminator was directed toward the putting surface to simulate direct sunlight. The resulting effect was very similar to viewing a putting green on a partly cloudy day with some direct sunlight. Once the putting green was installed, its speed was measured with a stimpmeter to be just over 10. This would be typical of tournament conditions on a high-quality golf course. Figure 1 illustrates one of the golfers putting on this setup while wearing the portable eye-tracking system.



Figure 1. The putting green configuration in use during these experiments. Note the diffuse bluish simulated daylight illumination and the direct yellowish simulated sunlight illumination. This golfer is wearing the portable eye-tracking system.

Task

The task for each golfer was to strike a total of 40 putts; 20 each on two different putting green setups. Both putts were slightly over eight feet in length. The first

setup (first 20 putts) was a relatively straight uphill putt. The rise from ball to hole was about 8 inches and the putt ultimately broke about one inch to the left. The second set-up (second 20 putts) was a right-to-left rollover. This putt was uphill (about 4 inches) for the first four feet and downhill for the last four feet while breaking about 6 inches to the left. The putting green has visible controls to set the contour of the putt. These were covered with gray cloth so that the golfers were not able to read the green by looking at the settings. Instead, they were forced to read the green based on the surface contour just as they would on a golf course. The golfers were not allowed to practice putting on either of the setups prior to data collection. This was done in order to allow eye-tracking data to be collected during the initial read of the greens and during any learning process that might occur over repeated putts. The result (make or miss) was recorded after each putt and the golfers were allowed to take a break after each set of 10 putts if desired. The golfers were also not allowed to view the putting green while its configuration was being set up.

Golfers

Four golfers (also the four authors of this research) completed the experimental tasks. At this time, the number of people for which data are collected is limited by the time required to configure and set up the eye-tracking device. The four golfers were selected to have a range of golfing experience and capabilities. This was done to check for significant differences across these different categories of golfers. The four are classified as novice, beginner, intermediate, and advanced. These four golfers are characterized as follows.

Novice - Despite being in his 20's, the novice golfer had never played golf or even putted (including miniature golf). This golfer is truly a novice and hadn't even stroked a putt before the data collection began.

Beginner - The beginner golfer was in his 40's, but also has never really played golf. However, he has some experience striking a golf ball and has experience playing miniature golf. While this was not the first time this golfer had touched a club, he is essentially a non-golfer.

Intermediate - The intermediate golfer is in his late 20's and has been playing golf regularly for approximately six years. He has taken some formal lessons, plays to a handicap of approximately 15-20, and would be considered a good putter. The intermediate golfer could probably be considered typical of an average amateur.

Advanced - The advanced golfer is in his late 30's and has been playing golf for approximately 30 years. He has competed in local amateur tournaments and on a scholastic golf team. He has had some formal coaching and instruction, but is largely self-taught. The advanced golfer plays or practices several times a week and holds a 3 handicap.

Eye-Tracking System

The portable eye-tracking system used in these experiments is described in reference 5 and illustrated in place on an observer in Figs. 2 and 3. From the golfer's point of view, the system consists of a modified pair of racquetball goggles and a small backpack. The goggles are constructed such that the right pupil is back illuminated using an infrared LED. A miniature video camera, sensitive only to infrared, monitors the pupil and the first surface reflection (on the cornea) through a series of mirrors. After careful calibration, fixation positions can be calculated from the centers of the corneal reflection and backlit pupil. The goggles are fitted with a second color video camera that records the same view as the golfer. A computer system in the backpack records both video images (infrared of the pupil and color of the viewed scene) and superimposes a cursor over the color video image to indicate the location in the scene that the golfer is looking at. The complete system is self-contained within the headgear and backpack such that the observer is free to move around at will.



Figure 2. One of the golfers wearing an earlier version of the custom-built portable eye-tracker headgear.



Figure 3. A view of the backpack containing the computer system and digital video recorder used to record eye-tracking data.

The output of the eye-tracking system is a video tape of the experimental session. The video tape corresponds to what was seen by the golfer during the session with the point of fixation (direct gaze) indicated by a small black cursor. A

picture-in-picture system was used to include the simultaneous infrared view of the pupil in a small window on the video. This image is used by the experimenters to assure accuracy of the tracking data. Figure 4 illustrates some sample frames from one of the video segments with crosshairs drawn in to highlight the point of fixation.

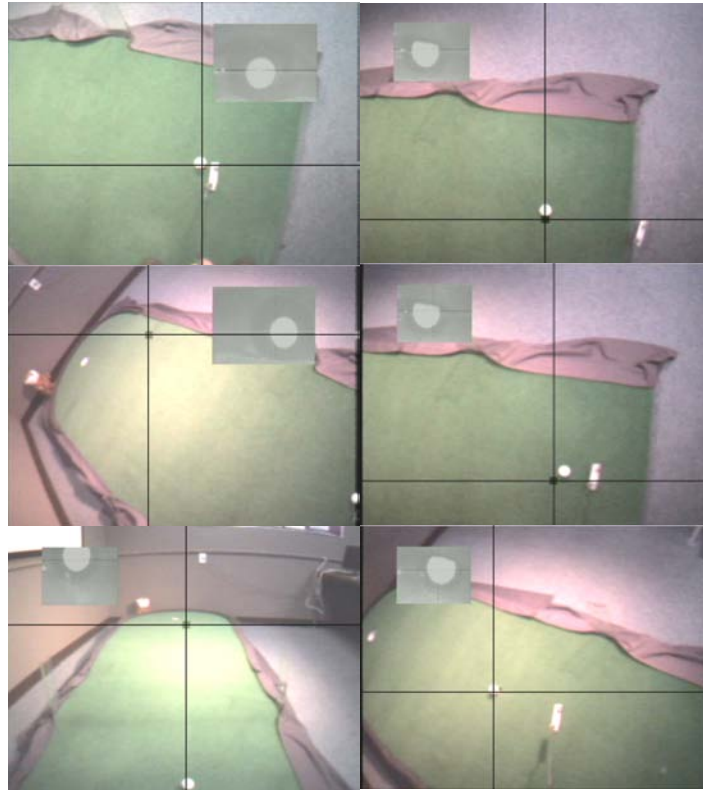


Figure 4. Several frames from an eye-tracking session video. The three frames on the left are during the green reading and setup for the putt while the three frames on the right are during a stroke. The black-and-white inset frame is the infrared view of the pupil and the crosshairs indicate the locus of fixation.

Analysis

Two types of analyses were performed on the data, qualitative and quantitative. The qualitative analyses were completed by simply viewing the recorded videos with eye-tracking results while noting impressions of what the various golfers were doing. This analysis was completed by three of the authors with detailed notes being completed by one of the authors, also the advanced golfer in these experiments. The results obtained by this qualitative analysis are similar to what might be obtained by a golf instructor viewing a video tape of a student during putting strokes. However, in this case the video shows the golfer's viewpoint rather than the instructor's. Much can be learned from simply viewing these videos. It is particularly enlightening for golfers to view tapes of their own putting strokes, just as it would be in a normal instructional setting. It is interesting to consider the potential future use of eye-tracking systems by golf instructors. All 40 putts by each of the four golfers were evaluated during the qualitative analyses.

The quantitative analyses consisted of careful recording of data on the location, duration, and number of fixations during each putting stroke. This was accomplished by transferring the digital video sequences to a Macintosh computer system on which the video could be analyzed frame-by-frame using the iMovie software system. Due to the large data volumes and time involved in frame-by-frame analysis of video, only 12 putts (six from each green setup) were evaluated for each golfer. This also allowed the experimenters to eliminate video during which the quality of the track was questionable. The 12 putts analyzed were selected based on the quality of the eye tracking and sampled to be representational of the overall set of 40 putts. The only constraint was that the first putt for each setup was included in case it yielded unique results (beyond the added time for green reading, it did not). This analysis focused on the three main locations of fixation during the putting process. These were the hole, the ball, the club. These locations of fixation will be referred to as H, B, and C respectively in the remainder of the report. In some cases there were intermediate fixation locations during the reading of the putt, but these were not found during the actual setup and stroke, which are the focus of the data discussed below. Data were recorded from the time the ball was placed in the putting position by an experimenter until the ball was stroked by the golfer. The data recorded were the locus of fixation (H, B, or C) and the duration of fixation (in video frames, then converted to seconds). The full sequence of fixations allows the examination of the process, the duration, and the consistency of the golfers routine. For example, the last four fixations were often in the sequence C-H-C-B. Having the duration of each of these fixations allows statistics on the steadiness, and consistency of the putting process. Some of the digital video sequences were then converted to QuickTime format to allow them to be archived on a web page for general viewing.

Results

Putting Performance

The golfers performed much as expected in terms of the relative numbers of eight-foot putts holed. The novice struggled to learn a putting stroke while making just one of 40 putts (3%). The beginner putted quite well holing 21 of 40 putts (53%). The intermediate golfer made 30 of 40 putts (75%) and a surprising, determined performance by the advanced golfer resulted in 40 of 40 putts made (100%). These data are also listed in table I. Recall that none of the golfers was allowed to practice these putts prior to data collection. While the relatively high number of putts made would be expected from repeated strokes of the identical putt, the first putt was made from scratch much as it would be in a round of golf. There was no significant difference in performance for the two putting-green setups.

Qualitative Assessment

This section provides some notes made upon viewing the video recordings for each of the four golfers.

Novice - The novice golfer tended to look quickly at the target twice before executing the stroke. The stroke itself was a short, choppy swing with no practice swings and little follow through. The novice did not read the green at

all and had no steady locus of fixation. Instead he looked quickly back and forth from the hole to the ball and then executed the stroke. After completing the stroke, the novice would follow the ball and then compare the location the ball stopped with the hole location in order to try to correct the error on the next attempt. Amazingly, the novice was often not looking near the ball when the stroke was made. Instead he was looking to the location that the backswing would end and once even looked at the grip during a stroke. During most attempts, the novices eyes were moving, rather than steady during the stroke. Both the location and duration of fixations were not consistent for this golfer. The overall impression of the session was that the putts happened very quickly. The entire session was completed in approximately 17 minutes.

Beginner - The beginner did take the time to read the green setups by viewing several intermediate areas of the green in preparation for the early putts. This golfer would look to the hole 2-3 times before stroking the ball. These were quick glances to the hole and never followed any intermediate path between the hole and ball. There is some suggestion that the intermediate golfer was focusing on the target significantly more than the novice, at least during the phase immediately before the stroke. Unlike the novice, the beginner did take advantage of the alignment markings on the putter to aid in squaring the clubface. The beginner's eye was fixed on the ball during the stroke itself and the stroke was smooth. On the missed putts, it was clear that the clubhead face angle shifted during the stroke and there was also evidence of significant body motion during some strokes. In some cases, the beginner would partially follow the clubhead back during the backswing and then return his gaze to the ball. The beginner was also relatively quick in completing the entire experimental session in about 15 minutes.

Intermediate - The intermediate golfer took the time to more extensively read the green prior to the first few putts on each setup. This golfer would usually view the hole once prior to putting. However, his gaze to the hole was of longer duration and tended to be more steady than those of the novice and beginner. The intermediate golfer's stroke appeared to be quite smooth and steady and certainly more consistent than the beginner or novice. On occasion, the intermediate golfer would make a practice stroke, but only quickly glance at the hole after the stroke. There was no indication that this practice was a full visualization of the putt. The intermediate golfer was more deliberate than the novice and beginner and took approximately 25 minutes to complete the putting sessions.

Advanced - The advanced golfer performed the most extensive read of the greens before the initial putts on each setup. This golfer viewed the entire surroundings more during the initial read, apparently to collect as much information as possible. During the process of reading the putt, the advanced golfer focused on the last foot or so of the putt, spending much of the reading time looking at that area. He then gradually moved his view back to the ball increasing the spacing of his viewed points as his gaze moved further from the hole. This indicates that the advanced golfer has learned to spend most of his time reading the putt in the area where the ball is traveling slowest and is most impacted by the contour of the

green. The advanced golfer approached each putt from behind and started the process by aligning the markings on the ball to point down the intended line of the putt. He would then move from behind the ball to take his putting stance while focusing his attention on the hole. It appeared that significant time was taken to study, and perhaps visualize, the path between ball and hole from behind the ball before taking the stance. Once the stance was taken, the advanced golfer took one practice stroke while viewing the location of an imaginary ball at the clubface. After the practice stroke, this golfer followed the path of the imaginary ball to the hole. This was clearly a sign of visualizing the putt and was done consistently on each of the 40 strokes. After addressing the ball, this golfer looked twice to the hole (only once after becoming fatigued late in the session), traced the path back to the ball and then executed the stroke. The golfer's eyes were on the ball and very steady during the stroke (closer analysis of the digital recording later showed that the golfer fixated the club to align it prior to the stroke and then retained that fixation point during the stroke. Thus his eye actually wasn't on the ball, but rather right next to it!). Some general impressions from the video of the advanced golfer included that he tended to fixate on the target (hole) for a longer duration than the other golfers before the stroke and that he had a very consistent routine with a very steady body. The session for the advanced golfer was also the longest, requiring about 30 minutes.

The qualitative analyses are quite consistent with traditional golf instruction on the putting stroke. They do provide some interesting feedback for the golfer, including excellent views of just what the clubhead is doing during the stroke and the ability to note any inconsistencies, distractions, or extraneous actions during the stroke. The above observations serve to reinforce the concepts in the Pelz books^{1,2} that it is important to be consistent, visualize the putt, and spend significant time viewing the target.

Quantitative Analyses

Several quantitative analyses of the eye tracking data were performed. It is worth noting that the approximately 1.5 hours of digital video, at 30 frames per second, provides over 160,000 frames to analyze for fixation location and duration. These data also represent over 19 gigabytes of digital video data. For these reasons (and the significant analysis time required), only 12 of the 40 putts (6 from each setup) were analyzed for each golfer. While there are essentially an infinite variety of metrics that can be obtained from the video, for the sake of simplicity and clarity, these were reduced to a few important parameters for discussion. These include analysis of the average and standard deviation of the number of fixations, and fixation durations for the last few fixations prior to striking the ball. In addition, the relative amount of time looking at each of the three main locations, B, C, and H, were evaluated. Lastly, the sequence of fixations was analyzed to look for any meaningful trends.

Table I includes the putting results and analysis of the number of fixations for each golfer. In the case of the advanced golfer, two sets of data are presented. One is for the final portion of the putting procedure from addressing the ball until the stroke, while the second is for the entire process including lining up the

ball and visualizing the path. The first set of data is more consistent with the process used by the other golfers and therefore a more direct comparison.

Table I. Putting results (for 40 attempts), average number of fixations and standard deviation in number of fixations (for 12 attempts) for each of the four golfers.

Golfer	Putts Made (%)	Avg. # Fixations	Std. Dev. (% of Avg.)
Novice	1 (3%)	9.0	3.9 (44%)
Beginner	21 (53%)	8.0	2.5 (31%)
Intermediate	30 (75%)	6.4	2.0 (32%)
Advanced	40 (100%)	7.8	1.2 (15%)
Advanced (Full Routine)		15.9	2.2 (14%)

The average number of fixations from addressing the ball until making the stroke are fairly consistent across the four golfers, ranging from about 6 to 9. The intermediate and advanced golfers do have slightly simpler routines, averaging one or two fewer fixations than the other golfers. The average number of fixations for the advanced golfer doubles from 8 to 16 when the full routine of lining up the ball and visualizing the ball's path to the hole from behind the ball is included. The standard deviations in the number of fixations provide some more interesting insight. The absolute value of the standard deviation drops from 3.9 for the novice down to 1.2 for the advanced golfer. This indicates that the advanced golfer has a much more consistent routine than the other golfers (a low standard deviation indicates that nearly the same procedure is followed on each putt). Expressed as a percentage of the mean number of fixations, this result becomes even more clear. The novice has a percent standard deviation of 44% indicating that the typical range of the number of fixations is about as large as the average number. The beginner and intermediate have values of about 30% indicating that they have significantly more consistent routines in terms of the number of fixations. However, the most marked change is the drop to a 15% standard deviation for the advanced golfer. This value is half that of the beginner and intermediate and one-third that of the novice. This result quantitatively confirms the observation that the advanced golfer was much more consistent in his putting routine. Examination of the full putting routine for the advanced golfer continues to confirm this result as the percent standard deviation remains nearly constant, dropping to 14%.

The impact of improved consistency in the putting routine on the putting results is illustrated quite clearly in Fig. 5 illustrating the percentage of putts made as a function of the standard deviation in number of fixations. Figure 5 clearly illustrates a relationship between these two metrics with the expected result that a more consistent routine (lower standard deviation) results in more putts made.

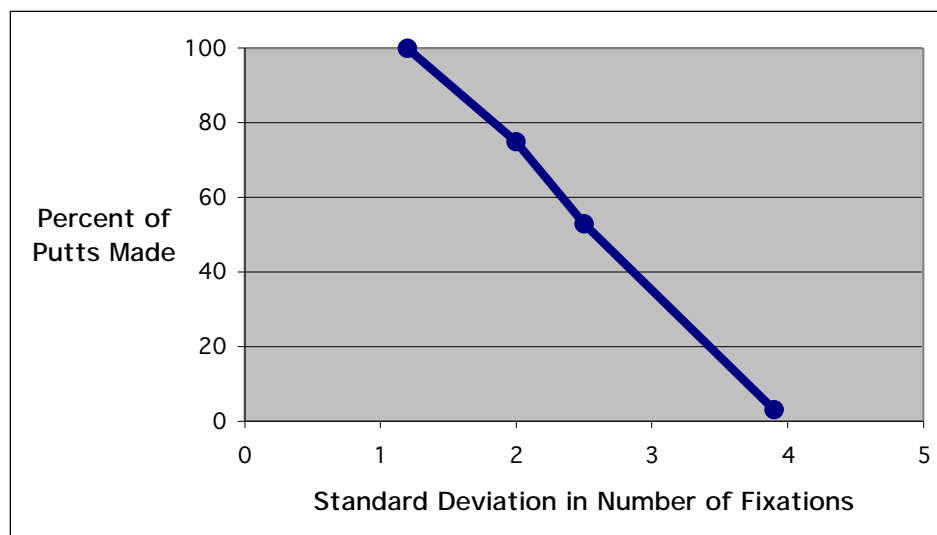


Figure 5. Percentage of putts made plotted as a function of the standard deviation in the number of fixations in the putting routine. A lower standard deviation indicates a more consistent putting routine which, in turn, appears to result in more putts made.

The next interesting piece of information to glean from the data is the steadiness of gaze, or typical duration of fixation. Since the four golfers have very different routines, it is difficult to make a fair comparison. To make such an inter-comparison more meaningful, it was decided to examine only the last four fixations prior to striking the ball. This number is appropriate since each golfer used at least four fixations prior to striking the ball on each attempt. Table II includes the average fixation duration, the standard deviation, the total duration, and the percentage of time fixated on the ball (B), club (C), and hole (H) during the last four fixations.

Table II. Data on the average duration and location of the last four fixations prior to striking the ball for each golfer. All durations are in seconds.

Golfer	Avg. Fixation Duration	Std.Dev. (%)	Total Duration	%B	%C	%H
Novice	0.51	0.57 (110%)	2.1	12%	58%	30%
Beginner	0.57	0.54 (94%)	2.3	11%	77%	12%
Intermediate	1.19	1.23 (104%)	4.7	67%	18%	15%
Advanced	0.88	0.45 (51%)	3.5	25%	52%	23%

Table II illustrates that both consistency and steadiness pay off in more putts made. The average fixation durations for the intermediate and advanced golfers are around one second while those for the novice and beginner are about one-half a second. This confirms that the more experienced golfers are spending more time viewing each target throughout the final stages of the putting process. Since these data are for the last four fixations, this directly translates into a longer time (about 4 sec.) for the more experienced golfers to complete this last phase of the putt in comparison with about 2 sec. for the inexperienced golfers. Once again, it is the standard deviation that provides an even more interesting insight. The advanced golfer has a percent standard deviation in fixation duration of 51% in comparison with values of approximately 100% for the other three golfers.

This indicates that the advanced golfer is again much more consistent in his putting routine.

The other important information in Table II is the locus of fixations expressed in terms of the percent of the time spent on each of the three main fixation points during the last four fixations. The advanced golfer spends approximately half his time viewing the club, and one quarter of his time viewing each of the hole and ball. This is consistent with the low standard deviation in fixation times and the consistent routine of the advanced golfer to have a C-H-C-B sequence for the final four fixations. Thus with two fixations on the club, one would expect the percent of time on the club to be double that of the other two targets. Interestingly, the beginner and intermediate golfers spend significantly less time viewing the hole (12 and 15% respectively). However, what they do with the remaining time is very different. The beginner spent most of it (77%) viewing the club, presumably focusing on getting it to do the desired job. On the other hand, the intermediate golfer spends nearly 70% of his time fixating on the ball. This golfer has obviously taken the advice of keeping your eye on the ball to heart. Perhaps most interesting is the result that the novice spends very little time looking at the ball (12%) and greatest percentage of time of any of the golfers viewing the hole (30%). The novice hasn't been taught anything else, so he is adopting the quite natural strategy of spending more time viewing the ultimate target, the hole. It is intriguing to consider that students of golf are so often taught to keep their eye on the ball, that later on they must be trained again to focus on the target and then execute the stroke. Since the ball isn't going anywhere and ultimately has no impact on the result (the location of the hole and motion of the club are the variables), so much thought about fixating on the ball is not really helpful.

The importance of spending some time viewing the hole is illustrated in Fig. 6 for the beginner, intermediate, and advanced golfers. The novice is omitted since his results were so inconsistent both in terms of the locus of fixation and the putting stroke itself. It is clear from Fig. 6 that spending a greater percentage of the last four fixations viewing the hole results in a greater number of successful putts. This is accomplished by the advanced golfer through his deliberate pace of long (about 1 sec.) fixations and the consistent routine of always viewing the hole just before executing the stroke.

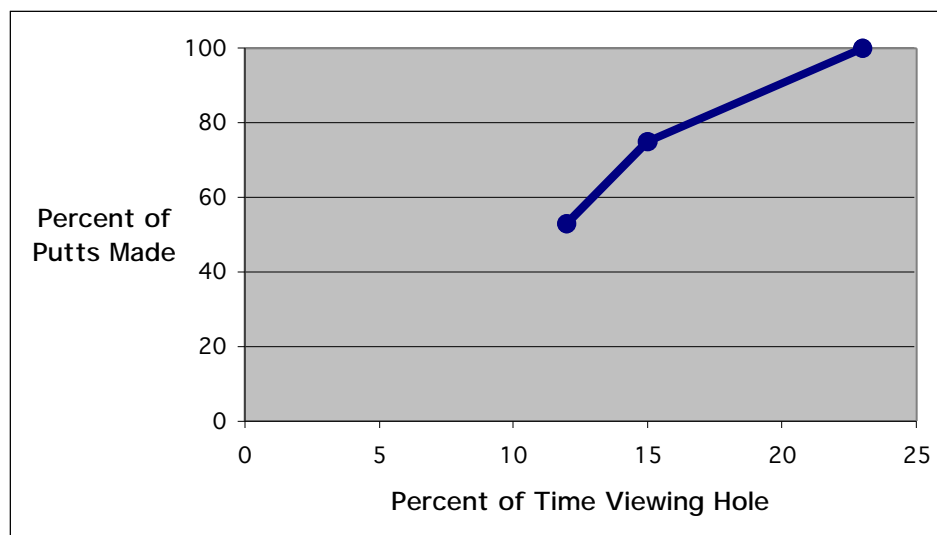


Figure 6. Percent of putts made as a function of the percent of time during the last four fixations spent viewing the hole.

It is also interesting to further explore the sequence of final four fixations prior to striking the ball. For the advanced golfer, the sequence was C-H-C-B for 11 of the 12 analyzed putts. The one exception was a putt during which the golfer was spoken to during the backswing. He changed his fixation sequence briefly, but continued the process and stroked the putt. In other words, the eyes were distracted, but the stroke was undeviated. In examining the other golfers, the intermediate golfer followed the same sequence on 5 of 12 putts. The other 7 putts for the intermediate golfer showed no consistent trend, although there were several cases when the hole was not viewed and he went back and forth from ball to club. Interestingly, the beginner also showed this same sequence, C-H-C-B on all 12 of his putts. His sequence was more consistent than the intermediate, but the duration of the fixations was shorter, so he was moving faster and the execution of the stroke itself was not as consistent. Perhaps a combination of the consistent stroke of the intermediate and the consistent final routine of the beginner would result in an improved putter. Lastly, the novice only followed the C-H-C-B routine on 3 of 12 putts. The others were very inconsistent and unpredictable for the novice.

A similar set of analyses was performed on the final six fixations for each of the golfers. In some cases, golfers did not use six fixations, so as many as were available were analyzed. The results were similar to those for the final four fixations and thus will not be discussed in further detail. They are included in Table III for the interested reader.

Table III. Data on the average duration and location of the last six fixations prior to striking the ball for each golfer. All durations are in seconds.

Golfer	Avg. Fixation Duration	Std.Dev. (%)	Total Duration	%B	%C	%H
Novice	0.57	0.55 (96%)	3.4	17%	52%	31%
Beginner	0.56	0.52 (92%)	3.2	10%	75%	15%
Intermediate	1.23	1.17 (96%)	6.6	63%	25%	12%
Advanced	1.08	0.65 (60%)	6.5	15%	53%	32%

Table III shows that the advanced golfer spent an even greater percentage of his time viewing the hole. This is confirmed with his sequence of the final six fixations, which is C-H-C-H-C-B. Working through this sequence, the golfer is viewing the club to align it properly and prepare to use it, the target to confirm the goal of the putt, repeating this process, and then finally viewing the ball once the backswing has started. Clearly the hole and the club are the important locations to collect visual data on. The ball is always in the same location assuming that golfer is consistent in taking his stance, thus there is no need to spend much time looking at it. The advanced golfer followed this sequence on 11 of 12 putts (again the exception being one putt in which he was interrupted). The intermediate golfer only followed this sequence once since he was spending his additional fixations viewing the ball instead of the hole. The beginner began to show some inconsistency in his sequence when six fixations are counted, but still followed this sequence on 9 of 12 putts. The novice only followed this sequence once. A significant point however is that this one putt was the only one made by the novice out of the 40 attempts.

Conclusions and Future Directions

This study of golfers' eye movements before and during the putting stroke has provided some interesting results and insights. Much of what was found confirms conventional golf instruction. However, it is clear that successful putting results from a greater focus on the hole (target) than the ball. This was one very significant difference between the intermediate and advanced golfers. It also became evident that looking at the ball really means looking at the club during a successful pre-shot routine. This confirms the relatively common instruction to view the target and keep a mental image of the target in your mind during the stroke and provides further quantitative evidence that the age-old concept of keeping your eye on the ball might be holding back improvement in some golfers. It is not difficult to find examples of golf instructors stressing the importance of viewing the target. For example, a recent instructional article on short wedge shots states "good players spend 80% (or more) of their pre-strike time looking at the target, 20% (or less) looking at the ball. Middle-and high-handicappers spend 80% on the ball, 20% on the target."⁸ This general concept is well borne out in the data and analyses reported upon here.

The other results found to lead to successful putting are steadiness and consistency. Steadiness was illustrated by relatively longer average fixation durations. The better golfers were spending more time looking at each location during their routine. This could be thought of as a calm and deliberate routine, something often taught as good pre-shot form. Consistency was illustrated by the standard deviations in the number and durations of fixations. By these measures, the advanced golfer was often 2-3 times more consistent than the others. Lastly, consistency was also illustrated through the sequence of fixation locations. The advanced golfer was unwavering in his sequence of viewing patterns for the 40 attempts.

The qualitative assessments of the results also point to the importance of focusing on the target and of visualizing the ball traveling down the path to the

hole and then executing the shot. Only the advanced golfer consistently performed these actions.

While the quantitative data are helpful and might be useful to golf instructors in helping their students to improve their game, it is perhaps the qualitative assessment of the captured video that might prove most useful in the future. Clearly students could learn a lot by objectively viewing what they were looking at as well as what their body and clubs were doing during the execution of a stroke. The golfers in this study were often surprised to learn just what they were looking at during the preparation for, and execution of, the putting stroke. This knowledge can certainly be beneficial in refining a putting routine, improving the overall stroke dynamics, and ultimately result in more putts made. The advanced golfer in this study seemed most aware of what he was looking at and eye-tracking videos such as those produced can only serve to make golfers more aware of their eye movements (and perhaps improve their games). Instructors could also use this information to analyze and assist in improving, the pre-shot routine, visualization techniques, stroke mechanics, alignment, and consistency.

Future research will aim to make the eye-tracking system even more portable and less intrusive. Ideally one day such a device would be no more difficult to use than slipping on a pair of sunglasses. Immediate improvements required include modifying the optical structure to allow outdoor use, removing the backpack by using wireless transmission of the signals from the video cameras to the recording systems, and further miniaturization of the entire headgear. It is hoped that some of these advances will come quite quickly. Others will take longer, but it is certainly possible to envision the day when PGA professionals will have eye-tracking apparatus in their toolbox alongside their video cameras and other tools. The ability to collect data from elite golfers such as the top touring professionals might also prove to be a great teaching tool for millions of golfers worldwide. It is hoped that this project will provide one small step in the direction of creating such tools by showing some of their potential benefit.

Further Information

Further information on this project is available on the internet at www.cis.rit.edu/fairchild/putting.html. On that website can be found QuickTime video clips of several putt attempts by each of the golfers as well as some additional video illustrating the function of the eye-tracking system. There is also a brief description of this project, a copy of this report available for download, a poster that was designed for display in the laboratory to explain the presence of the putting green, and any updates that post-date this report. Readers are encouraged to visit the website to gain further insight into the information that can be obtained by the eye tracker.

References

1. D. Pelz and N. Mastroni, *Putt Like the Pros*, Harper Perennial, New York, 1989. (pp. 114-117)
2. D. Pelz and J.A. Frank, *Dave Pelz's Putting Bible*, Doubleday, New York, 2000. (pp. 222-232)

3. K. Harmel, "'Quiet Eye' is the Key to Making the Shot, Says UF Sports Researcher," reprinted from *ScienceDaily* Magazine at <<http://www.sciencedaily.com/releases/1999/06/990615154337.htm>>.
4. <<http://www.cis.rit.edu/people/faculty/pelz/>>
5. J.B. Pelz, R. Canosa, J. Babcock, D. Kucharczyk, A. Silver, and D. Konno, "Portable Eyetracking: A Study of Natural Eye Movements," *Proceedings of the SPIE, Human Vision and Electronic Imaging*, San Jose, CA: SPIE (2000).
6. <<http://www.puttgolf.com>>
7. <<http://www.cis.rit.edu/Fairchild/putting.html>>
8. M. Hall and M. Gearen, "Hitting Wedge Shots Closer to the Hole Like Tiger," *The Majors of Golf 2001: The PGA Championship*, (2001). (pp. 38-40)