FISHER, KEVIN, M.S. The Time Course of Attention during Two Golf Putts of Different Lengths in a Group of Experienced Golfers. (2011)
Directed by Dr. Jennifer L. Etnier. 80 pp.

Previous research using the dual-task paradigm to assess the time course of attention has been conducted with many sport-specific movements, such as a tennis serve, a volleyball set, a horseshoe pitch, and a basketball free-throw. However, this line of research has not been applied to a golf putting stroke which differs from previous sport skills because it requires that participants strike the ball with a club rather than propelling it directly from their hands. In the current study, a dual-task paradigm was used to investigate the time course of attention during two golf putts: one from 6 feet (easy condition) and one from 12 feet (difficult condition). A sample of experienced golfers (N = 20) with a handicap of 17 or less participated in the study. Participants were asked to respond verbally to an auditory tone presented at three probe positions during the two putts. The order of the putts and the presentation of the auditory cue at each probe position were randomized and catch trials were used to prevent anticipatory effects. The first hypothesis of this study stated that the time course of attention would follow a similar pattern for both shots. Specifically, it was hypothesized that attentional demand would be greatest just before the putter contacted the golf ball. The second hypothesis of this study stated that the increased task difficulty of the 12-foot putt would result in greater overall attentional demand during this putt than during the 6-foot putt.

The results of a repeated-measures analysis of variance (ANOVA) for putting performance indicated no significant differences in the level of performance ($p > .05$) for probe positions across the short putt. However, a repeated-measures ANOVA for putting

performance on the long putt indicated that participants' level of performance changed based on probe position ($p < .05$). Based on previous research, these findings suggest that the time course of attention cannot be accurately assessed in the long putt; this conclusion is due to a reprioritization of the primary and secondary tasks that is indicated by inconsistency in performance across probe positions. The results of a repeated-measures ANOVA for reaction time during the short putt showed that there were no significant differences in reaction time at each probe position ($p > .05$), indicating that attentional demand remains constant throughout the putting stroke. The results of a repeated-measures ANOVA for reaction time also indicated that reaction times on the long putt were significantly higher than reaction times for the short putt ($p < .05$), indicating that the long putt required an overall higher level of attentional demand than the short putt. These findings suggest that experienced golfers demonstrate a constant level of attentional demand throughout the putting stroke on a 6-foot putt. These findings also suggest that experienced golfers were unable to maintain primary task performance on the 12-foot putt and that the 12-foot putt required higher attentional demand than the 6-foot putt as a result of increased task difficulty.

THE TIME COURSE OF ATTENTION DURING TWO GOLF PUTTS OF DIFFERENT LENGTHS IN A GROUP OF EXPERIENCED GOLFERS

by

Kevin Fisher

A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Greensboro
2011

Approved by

____
Committee Chair

For Mom and Dad,
who worked hours long and hard
so that I would have the opportunities
that they never had.

APPROVAL PAGE

This thesis has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

Committee Chair ______________________________

Committee Members ______________________________

____

____
Date of Acceptance by Committee

____
Date of Final Oral Examination

ACKNOWLEDGEMENTS

Many thanks to Dr. Jennifer Etnier for her support, guidance, and friendship throughout this project and my graduate career.

Thank you to my thesis committee members, Dr. Bob Christina and Dr. Kurt Kornatz. I appreciate your input, guidance, and help along the way. Additionally, I would like to thank Dr. Randy Schmitz for taking the time to help me with software programming.

Also a special thanks to the following people: Amanda Williams, Ben Austin, Brad Davis, Bryan Loy, Efferman Ezell, Enoch Chow, Erin Reifsteck, Jeff Labban, Jody Nelson, John Evans, Matt Shilling, and Sam Fisher. Not only do I appreciate your help with my study, but I value your friendship.

Finally, a special thanks to my mom and dad for supporting me and helping me with the planning and construction of the putting green platform for this study.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In the field of psychology, attention has been studied extensively since the nineteenth century. Intuitively, it is clear that we can only attend to a limited number of things at one time, and our performance on a task may suffer if attentional resources are strained. William James (1890) defined attention as "The taking possession of mind in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, and consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others…" (p. 381-382). This definition suggests that attentional capacity is limited and that conscious effort is required to focus on the desired object or task; in other words, a person must be selective about where to allocate attentional resources.

The capacity theory of attention states that each person possesses an overall pool of attentional resources and this pool has a general limit with regards to information capacity (Knowles, 1963). Attention may be allocated freely between multiple tasks, but interference will occur and task performance will suffer if the combined attentional demands exceed capacity. The amount of interference that occurs is directly related to the amount of attention that each task requires. Therefore, a task requiring a low amount of attention would leave plenty of attentional resources to complete another task while a task requiring a high amount of attention would leave fewer resources to complete another task and be more likely to cause interference. When attentional capacity cannot meet the task demands, interference will cause performance to suffer or fail.

In order to determine the time course of attention of an activity, the dual-task paradigm is often used. In this paradigm, participants are asked to perform two tasks simultaneously: a designated primary task and a designated secondary task (Kahneman, 1973). Performance on each task is first measured independently in order to establish a baseline for performance. Then both tasks are performed together, and the quality of performance on the secondary task provides a measure of the attentional load imposed by the primary task. Although the primary task could be almost anything that requires attention, the secondary task typically involves a different form of sensory input to reduce interference between the two tasks that is due to sensory overload as opposed to attentional demands (Beauchet, Dubost, Aminian, Gonthier, & Kressig, 2005). For example, a primary and secondary task that both involved auditory stimuli would lead to greater interference than having one task that involved mainly visual stimuli and another that involved mainly auditory stimuli. The secondary task is also often much less demanding than the primary task to help ensure that the tasks are not reprioritized. A secondary task may consist of a verbal response to an auditory cue as in Sibley and Etnier (2004) or Price et al. (2009). Performance on the secondary task may be assessed using a form of the dual-task paradigm called the reaction time probe technique.

The reaction time probe technique assumes a fixed, non-changing attentional capacity to perform two tasks simultaneously; the secondary task is designated as a reaction time task (Abernathy, 1988). If the primary task requires a large amount of a person's attentional capacity, he or she will have less attention to devote to the reaction time task and reaction time will suffer as a result. Reaction times are measured over the course of probe positions that are established for an activity, and both the peak of attentional demand during the activity and the time course of attention during the activity may be mapped. Slow reaction times indicate a large amount of attention being devoted to the primary task at a particular time while fast reaction times indicate a small amount of attention being devoted to the primary task at a particular time. Essentially, a person's reaction time on the secondary task will vary in order to maintain performance on the primary task. The reaction time probe is a useful technique for determining the time course of attention for tasks in sport settings.

The reaction time probe technique has been used to measure the time course of attention in several sport-related tasks. Castiello and Umilta (1988) conducted a series of studies using the dual-task paradigm on sports such as volleyball, running, and tennis. In the first study, volleyball players received a serve and results indicated that attention was greatest just before the ball was received. In the second study, sprinters and hurdlers were tested. For both events, the time course of attention was similar with attentional demand being greater at the first and last probe positions of the race when compared to probe positions in the middle of the race. In the third study, tennis players were tested using the reaction time probe technique during the return of a serve. Results indicated that attentional demand was greatest when the ball contacted the ground just before the player returned the serve.

Additional studies of various sport-specific tasks have also been conducted. In a study of precision pistol-shooting as a function of skill level, Rose and Christina (1990) found that reaction time results were distributed similarly across skill levels. Results also demonstrated that the level of attention directed toward the primary task of shooting increased linearly until the point immediately prior to the shot. Prezhuy and Etnier (2001) asked experienced horseshoe pitchers to perform horseshoe throws under dual-task conditions at two levels of task difficulty by manipulating the height of the stake. Results showed that reaction times were fastest during the backswing prior to the pitch, suggesting that the least amount of attentional resources were focused at this position. Results also indicated that reaction times were slower at all positions during the difficult task condition when compared with the easy task condition, suggesting greater attentional demand during the difficult condition.

In a study of time course of attention and decision-making during a volleyball set, Sibley and Etnier (2004) had participants perform either a simple set in volleyball or a decision-based set in which they had to choose between either a front set or back set. Results showed that overall attentional demand was increased when compared to the simple condition, and reaction times were slowest at the beginning of the ball flight and fastest during the middle portions of the ball flight. There was also an increase in attentional demand during the last portion of the ball flight while participants processed proprioceptive information and made accuracy adjustments during contact. In another study of sport-related attention, Price (2009) examined free throw shooting under dual-task conditions. Results showed significant differences between baseline reaction time and Probe Positions 1 and 2, which took place as the ball was being brought up to the chest and just before the ball was released, respectively. These results suggest that the pre-shot routine of a basketball free throw requires the greatest attentional demand, followed by the upward motion of the ball just before release.

Although research on the time course of attention has not examined all sports, this research suggests two broad attentional patterns for sport activities: one for the situation in which the athlete is about to receive a moving object and one for the situation in which the athlete is about to propel a stationary object. In the first pattern, attentional demand is increased when the object is about to be received because the athlete is attempting to determine critical information such as its direction and velocity. This pattern of attention may be seen in the results of Sibley and Etnier (2004) and the volleyball and tennis studies of Castiello and Umilta (1988). In the second pattern, in which an athlete is about to propel an object, attentional demand is greatest just before the object is propelled because the athlete is attempting to process important sensory information immediately prior to performing the task, and he or she is making last-second adjustments that will lead to a successful outcome. This pattern of attention may be seen in the results of Rose and Christina (1990), Prezhuhy and Etnier (2001), and Price et al. (2009).

Purpose and Hypotheses

The purpose of this study was to use a dual-task paradigm to determine the time course of attention during a task that required a participant to accurately propel a stationary object using an implement. Specifically, the task to be examined was a golf putt which may exhibit different attentional requirements than have previously been observed as a result of the need to control an implement to strike and propel a stationary object with great accuracy. The most similar task which has been studied in previous research is a tennis serve (which differs because the object to be struck is moving and the accuracy demands are not high). In this study, the effect of task complexity on attentional demands was examined by asking participants to perform golf putts at two different distances. Understanding the attentional demands of this type of motor skill and examining potential differences as a function of task complexity extends previous psychology and motor control literature concerning attentional demands of sport. Lastly, the data collected for this study was divided into two tiers based on handicap and three tiers based on putting performance. Low-handicap golfers were compared to high-handicap golfers, and good putters were compared to poor putters on patterns of attentional demand to see if any differences exist. Ultimately the findings of this study may help improve putting performance and training techniques by identifying the point at which attentional demand is greatest during a putt.

Based on previous research, the first hypothesis of this study was that the time course of attention is similar for both putts. Specifically, attentional demands are expected to be the highest just before the putter impacts the golf ball (reaction times will be slowest during this probe position). Previous research indicates that task difficulty may be defined as a function of the complexity of the task and the performer's experience with the task (Wulf, 2007). In regards to this study, the longer putt was considered more complex than the shorter putt because of the increased force required to propel the ball to the cup. As a result, the second hypothesis of this study was that the overall attentional demand of the longer putt is greater than that of the shorter putt. Also based upon Wulf's (2007) research, the third hypothesis of this study was that the attentional demands observed differ as a function of the skill level of the performer

CHAPTER II

REVIEW OF LITERATURE

William James (1890) defined attention as "The taking possession of mind in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, and consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others…" (p. 381-382). This definition suggests that attentional capacity is limited and requires conscious effort to focus on the desired object or task; in other words, a person must be selective about where to allocate attentional resources.

There are three major models for describing attention. The structural theory of attention suggests that information processing is limited by structural properties of the system (Kahneman, 1973). Another name for the structural model of attention is the bottleneck model, which suggests that a person's motor response to sensory input is constrained by a "bottleneck" in the various stages of attention. According to this model, people attend to things in three steps: sensory registration and storage, perceptual analysis, and response selection. While we can register many things with our senses at once, information flows into the bottleneck in the stages of perceptual analysis and response selection so that we can only analyze multiple stimuli or select multiple responses in succession rather than simultaneously.

An example of a bottleneck model of attention is the filter model put forth by Broadbent (1958), which suggests that information enters the senses and short-term memory store and is subsequently passed through a selective filter that keeps the information processing system from becoming overloaded (Styles, 2006). Two main types of filter models include early and late filter models. Early filter models suggest that multiple streams of information can only be processed in parallel in the early stages of stimulus identification such as sensory encoding and perceptual analysis (Schmidt and Lee, 2005). Once these streams of information reach the filter, only one stimulus at a time is processed through it in a single channel. In contrast, a late filter theory of attention suggests that the bottleneck comes later in stimulus identification and that multiple streams of information can be processed in parallel right up to the response selection stage (Styles, 2006). Only the information that passes through this filter enters a single limited capacity channel, where it is passed on for further processing and eventually long-term memory. Information that does not pass through the filter is lost.

Another model of attention is called multiple resource theory, which suggests that there are several "pools" of attentional resources rather than a single overall resource. Some examples of these pools include auditory attention, visual attention, and spatial attention. Each of these pools has its own capacity and is designed for specific types of information processing. During information processing, this theory proposes that there are a number of resources that may be required by a task and that multiple tasks will only interfere with each other if they compete for the same resource (Styles, 2006). Thus, tasks that are similar in nature will likely involve skills that require similar forms of attention.

As discussed by Young and Stanton (2007), a good example of multiple resource theory can be seen in a study conducted by Babel (1991), in which participants were required to give verbal commands to a processing control system while also performing a secondary task. The secondary task varied by being either verbal or spatial in nature, and results showed that participants were quicker if the secondary task was spatial rather than verbal. These results are consistent with multiple resource theory because it suggests that the verbal secondary task interfered more with the verbal primary task than did the spatial secondary task; presumably because the two verbal tasks were drawing from the same limited attentional resource pool. By drawing from the same pool, the two similar tasks placed greater requirements on the system than did the two different tasks and performance decreased as a result.

The final major theory of attention is the capacity model, proposed by Knowles (1963). Unlike structural theories, this model assumes that there is a general pool of processing resources, and this pool has a general limit with regards to information capacity. Attention does not have to be directed toward one task at a time as in a bottleneck model; instead, capacity theory states that attention may be shared between tasks in degrees (Styles, 2006). Although capacity is limited, it can be divided freely among several activities. Different mental activities require different amounts of attention, and interference will occur between activities if attentional capacity is exceeded. When the supply of the limited capacity does not meet the demand, performance will falter or fail entirely. While the structural model (bottleneck model) suggests that interference is specific and caused when tasks call for the same mechanisms of perception and response, the capacity model suggests that interference is nonspecific and depends only on the demands of both tasks. Capacity theory also states that interference occurs even when the total load on the system is below total capacity; however, the amount of interference increases as load on the system increases.

The capacity model suggests that attention is selective, which means that a person can intentionally control the allocation of attention. The amount of attention that is allocated to a perceived object or event affects processing in several ways (Kahneman, 1973). Attended events are more likely to be perceived consciously and in detail, they have a better chance of eliciting responses, and they are more likely to be stored in permanent memory. This connection between attention and memory is an important one. In order for information or events to be coded into long-term memory from short-term memory and sensory processing stores, they must be attended to in some way. To differentiate between conscious (controlled) and unconscious (automatic) attention, some researchers have divided attention into two domains: Domain A and Domain B (Styles, 2006). Domain A is high-capacity, unconscious, and requires no effort on the part of the individual. Domain B is small-capacity, conscious, and must be actively controlled by the individual.

Capacity theory states that attention can be allocated between two tasks with a great deal of freedom, but it also states that different tasks will demand different amounts of attention. Demand denotes that an activity cannot be performed without a certain required allocation of attention. A task classified as “easy” will require little attention and leave adequate attentional resources for the secondary task. In contrast, a task classified as “difficult” will require greater attention and leave fewer resources available for the secondary task (Styles, 2006). To test the effects of task difficulty on attentional resources, Posner and Rossman (1965) asked participants to retain three letters for a brief interval while simultaneously performing mental tasks of increasing difficulty. The amount of retention decreased with increasing difficulty of the mental task, suggesting that the task of highest difficulty led to the most capacity interference on attention. In order to test task difficulty and the amount of attention required for a given task, the dual-task paradigm was developed.

Generally, there are two distinguishable modes of controlling information processing that are relevant to expertise: “automatic” processing and “controlled” processing (Styles, 2006). Automatic processing takes place outside of conscious awareness, it occurs rapidly, it is parallel in nature, and it is carried out involuntarily (Schmidt and Lee, 2005). In contrast, controlled processing is deliberate, serial in nature, and conscious, and it can only deal with a limited amount of information at a particular time. Controlled processing requires attention whereas automatic processing does not, and it tends to be slow, particularly when there are numerous environmental cues and possible responses (Abernathy et al., 2007). Since automatic processing is involuntary, it is not interfered with by other tasks and it cannot be inhibited. Controlled processing is subject to interference from other tasks, but it can also be used flexibly according to a person’s intentions. Although sports skills require both automatic and controlled processing, physical skills become more automatic when they are practiced over time, which means that they are carried out using increasing amounts of automatic control and subsequently require less attention as expertise is achieved.

Skilled performance of a task generally requires two elements: strategic, cognitive planning and rapid, accurate motor response (Styles, 2006). While physical skills can be improved through practice and experience, attentional skills can also be improved by training. Individuals who have become skilled (experts) through practice require less attention to perform both cognitive and motor aspects of a task than novices because these aspects of task performance have become automatic in experts and therefore involve little demand on working memory. Research by Beilock et al. (2004) has demonstrated, for example, that experts actually improve under speed conditions while novices' performance declines. It is hypothesized that this difference occurs because experts are using automatic processes that are rapid, while novices are using controlled processes that require more information processing time.

In research on the time course of attention or attentional demand, the dual-task paradigm is often used. In the dual-task paradigm, participants are asked to perform two tasks simultaneously: one task that has been classified as the primary task and one task that has been classified as the secondary task. Initially, participants perform the primary and secondary tasks separately in order to assess performance on each one of these tasks before combining them. This step gives researchers a performance baseline to compare with performance observed during the dual-task conditions. Then performance on the secondary task is measured while both tasks are performed simultaneously in order to determine the attentional demands of the primary task. Although the primary task could be almost anything that required attention, the secondary task typically involves a different form of sensory input to reduce interference between the two tasks (Beauchet, Dubost, Aminian, Gonthier, & Kressig, 2005). For example, a primary and secondary task that both involved auditory stimuli would lead to greater interference than having one task that involved visual stimuli and one that involved auditory stimuli. In order to help ensure that the tasks are not reprioritized, the secondary task is often much less demanding than the primary task. For example, the secondary task may consist of pressing a button or providing a verbal response to an auditory cue as in Sibley and Etnier (2004). Performance on the secondary task may be assessed using the reaction time probe technique.

There are many different types of secondary tasks that may be used to measure performance in the dual-task paradigm. However, the two main categories of secondary tasks are continuous tasks and discrete tasks (Abernathy et al., 2007). As the name suggests, a continuous task places demands on attentional resources for the duration of the primary task, whereas a discrete task may be used at specific points. An example of a continuous task would be asking participants to perform mental arithmetic. While the difficulty of a continuous task can be manipulated to provide an index of attentional load, it is not very effective for identifying attentional changes during specific phases of the primary task. Discrete secondary tasks are better suited for precise timing of attentional demands, and one of the most commonly used discrete secondary tasks is the reaction time probe technique.

In the motor learning and sport psychology literature, the attentional demands of a motor task have typically been measured using a form of the dual-task paradigm called the reaction time probe technique (Castiello & Umita, 1988). This technique assumes a fixed, non-changing attentional capacity and researchers designate the secondary task as a reaction time task and establish probe positions that take place over the course of the primary task. Participants are then given a stimulus that requires some form of response at each one of these probe positions, and the reaction time of this response is measured at each position and compared with a baseline performance to assess differences in attentional demand of the primary task. The rationale behind this technique is that the primary task will require a certain portion of the participant's attentional capacity, and this requirement will affect performance on the secondary task. Therefore, changes in performance (reaction time) on the secondary task indicate changes in the attentional demand of the primary task.

It is important to note that when using the reaction time probe technique, performance on the primary task must be maintained when the secondary task is present. If performance falters on the primary task under dual-task conditions, it is possible that the participant has reprioritized the two tasks and thus confounded any conclusions that might have been drawn (Young and Stanton, 2007). Such a scenario can be monitored in a research design by including a measure of participants' performance on the primary task. As in Price et al. (2009), a points system was used with basketball free throw shooting in which participants received zero points for a complete miss, one point for hitting the rim, and two points for making a basket. In order to ensure that free throw shooting remained the primary task in this study, participants were required to maintain their level of performance based on the scoring system in both single-task and dual-task conditions. Decrements in performance of the primary task are more likely to be avoided if the secondary task requires a different attentional resource than the primary task. For this reason, verbal response to an auditory tone is typically chosen as the secondary task in studies involving motor skills. Under this condition, the reaction time probe is a useful technique for determining the time course of attention for tasks in sport settings.

In a series of studies by Castiello and Umilta (1988), the reaction time probe technique was used to measure the time course of attention for several sports including volleyball, running, and tennis. In their first experiment, volleyball players received two types of serves (a floating serve and a jump serve), and the reaction time of the receiving players was measured with three probe positions during the course of the serve: when the ball was about to be served, when the ball was above the net, and when the player was about to receive the ball. Overall, results indicated that attentional demand was greater for the floating serve than for the jump serve, and attentional demand was highest for both serves as the player was about to receive the ball.

In a second experiment by Castiello and Umilta (1988), eight 100-meter sprinters and eight 110-meter hurdlers were tested with the reaction time probe technique. There were four probe positions throughout the race for sprinters while there were five probe positions throughout the race for hurdlers. For both events, the time course of attention was similar with attentional demand being greater at the first and last probe positions of the race when compared to probe positions in the middle of the race. Overall attentional demand was also greater for the hurdlers than the sprinters.

In a third experiment by Castilello and Umilta (1988), eight tennis players were tested with the reaction time probe technique during the return of a serve. There were four probe positions that were tested including the initiation of the serve, when the ball reached the net, when the ball contacted the ground, and when the player was about to return the ball. Results indicated that all probe positions showed a significant increase in reaction time when compared to the control condition, which simply consisted of participants' response to the auditory cue alone. Results also indicated that attentional demand was greatest during the probe position in which the ball contacted the ground.

Rose and Christina (1990) performed a study of the time course of attention during precision pistol-shooting using a dual-task paradigm. Participants included novice, sub-elite, and elite shooters, and they were asked to respond to an auditory tone by pressing a button. The auditory tone was presented through headphones at six different probe positions. Results indicated that probe reaction time results were distributed similarly across all skill levels. Results also demonstrated that the amount of attention directed toward the primary task of shooting increased linearly until the point immediately prior to the shot.

Under dual-task conditions, Prezhuy and Etnier (2001) asked experienced horseshoe pitchers to perform horseshoe throws (the primary task) at two levels of task difficulty by manipulating the height of the stake (the target). The secondary task in this study was to respond to an auditory tone presented at three probe positions that were designated during the throw. Probe position 1 was the initiation of the pitch, probe position 2 was full extension of the backswing, and probe position 3 was the point just prior to the release of the horseshoe. Catch trials, in which there was no auditory tone, were used randomly throughout the experimental procedure in order to prevent anticipation effects. Results showed that reaction times were fastest at probe position 2, suggesting that the least amount of attentional resources were focused at this position. Results also indicated that reaction times were slower at all positions during the difficult task condition when compared with the easy task condition. This finding suggests that participants were using more attentional resources during the difficult task condition.

In a study of time course of attention and decision-making during a volleyball set, Sibley and Etnier (2004) had participants perform either a simple set in volleyball or a decision-based set in which they had to choose between either a front set or back set, and they used the dual-task paradigm to measure participants' reaction times during these two conditions. Results showed that reaction times were slowest at the beginning of the ball flight, when participants were using visual resources to gather information about the speed and direction of the ball in order to intercept it. Reaction times were fastest during the middle portions of the ball flight (indicating lowest attentional demand), and there was an increase in reaction time and attentional demand during the last portion of the ball flight while participants processed proprioceptive information and made accuracy adjustments during contact. In the decision-making condition, overall attentional demand was increased when compared to the simple condition, and the addition of the decision-making requirements led to a small but significant decrease in setting performance when compared to the simple condition.

In Price et al. (2009), a series of free throws constituted the primary task and response to an auditory tone was the secondary task. Participants (n=30) responded verbally to the tone, and their reaction time was measured at each of four probe positions that were distributed over the course of a free throw. Reaction time was examined and each of these probe positions was compared with baseline reaction time. Results showed significant differences between baseline reaction time and Probe Positions 1 and 2, which took place as the ball was being brought up to the chest and just before the ball was released, respectively. These results suggest that the pre-shot routine of a basketball free throw requires the greatest attentional demand, followed by the upward motion of the ball just before release.

In 2002, Beilock et al. performed an experiment to assess the effects of the dual-task paradigm on experts in golf. In this study experienced golfers performed a putting task under both single-task and dual-task conditions. In the single-task condition, participants were asked to say the word “stop” at the end of their putting stroke; in the dual-task condition, participants were asked to putt toward a target while responding to auditory tones by saying the word “tone”. Results showed that experienced golfers performed better in the dual-task condition than the single-task (termed the skill-focused) condition. Under single-task conditions, it was suggested that the expert golfers were consciously processing specific steps of performance rather than allowing automatic processes to take over and that their performance suffered as a result. However, under dual-task conditions their performance on the putting task was suggested to be automatic due to the addition of another task and thus their performance was not negatively affected.

Previous research on different sports suggests that the time course of attention should be measured for specific tasks. Although research on the time course of attention has not examined all sports, this research suggests two broad attentional patterns for sport activities. The first pattern occurs when the athlete is about to receive a moving object. Attentional demand is increased when the object is about to be received because the athlete is attempting to determine critical information such as its direction and velocity. This pattern of attention may be seen in the results of Sibley and Etnier (2004) and the volleyball and tennis studies of Castiello and Umilta (1988). The second pattern occurs when an athlete is about to propel an object, and attentional demand is greatest just before the object is propelled because the athlete is attempting to process important sensory information immediately prior to performing the task. The athlete is also making last-second adjustments that will lead to a successful outcome. This pattern of attention may be seen in studies such as Rose and Christina (1990), Prezhuhy and Etnier (2001), and Price et al. (2009).

CHAPTER III

METHODS

Participants

Participants consisted of 20 male golfers ranging in age from 20 to 71 years (mean age of 35.85 with a standard deviation of 17.78 years). All participants were right-handed and the inclusion criteria required that participants have a moderate golf handicap or better. Inclusion was based on self-reported golf handicap. Participants' handicaps ranged from -17 to 2.4 strokes (*M*=-9.31; *SD*=5.83 strokes). Each participant also reported their cumulative number of years playing golf. The range for years of golf experience was from 9 to 56 (*M=21*.75; *SD=14*.72 years). Additionally, 10 out of 20 participants had competitive golf experience at the high school level and, out of these 10, three had competitive golf experience at the college level.

Design

This study utilized a 2 x 3 design with repeated measures on both factors. One independent variable for this study was task complexity; this variable was defined as either a putt of 12 feet (high difficulty) or 6 feet (low complexity). The second independent variable of this study is probe position. Probe position consisted of three levels for reaction time analyses: probe position 1 (PP1) at the initiation of the backswing, probe position 2 (PP2) at the end of the backswing, and probe position 3 (PP3) just before the putter impacted the golf ball. These probe positions were determined by photocells that emitted a beam of light; when the beam of light was broken by the putter, the auditory stimulus (beep) was generated. For performance analyses, probe position consisted of these same three levels plus a fourth level for the catch trials. The dependent variables of this study were participants' performance on the putting task and their reaction time to the auditory tone.

Materials

A putting green was constructed out of plywood sections that measured 8 feet wide, 16 feet long, and 4 inches high when combined. A regulation size golf cup (4.25 inches) was placed in the center of the platform and the surface was covered with green indoor/outdoor carpet. Two black dots were placed on the carpet to mark the distances of 6 feet and 12 feet. Participants used their own putter and were provided with 12 Titleist Pro V1 golf balls. The auditory stimulus in this study consisted of a brief tone (beep) that was generated by the computer software program Lab View 2010. There were three software programs that were used in conjunction with each of the three probe positions. The appropriate program was chosen prior to each trial based on a sequence of randomly generated numbers, and this sequence was the same for all participants. The software program had to be manually started by the experimenter prior to each trial by clicking the "run" function within the program; this step was done once the participant addressed the golf ball. The tone was generated by computer speakers when the putter broke a beam of light emitted by one of two photocells near the putter. The first photocell was used for PP1 (initiation of the backswing) and PP3 (prior to impact of the golf ball) while the second photocell was used for PP2 (the end of the backswing). Due to the fact that the putter shaft is very thin, a 3 x 5 index card was taped to the shaft of the putter so that the photocells would work consistently. The index card provided a surface area that was large enough to break the beam of light emitted by the photocell. An Olympus WS-400S Digital Voice Recorder was used to record participants' verbal responses to the auditory stimulus. An Olympus microphone was used in conjunction with the voice recorder and was clipped to each participant's shirt. The participant kept the voice recorder in a pocket while putting and the microphone cord was placed under the participant's shirt so that it would not interfere with the putting task. Finally, the audio software program Audacity 1.3 was used to analyze participants' verbal responses and acquire reaction time data.

Procedure

Participants performed in one study session lasting approximately one hour. Prior to the start of each session, participants reviewed and signed an informed consent agreement that had been previously approved by the university's Internal Review Board and filled out a demographic questionnaire (see Appendix A). Upon completion of these forms, the experimenter provided instructions to each participant with regards to what they would be doing for the duration of the study, how many putts they would be hitting, and how they should respond to the auditory tone. Participants were then asked to select a piece of paper at random to determine whether they would perform the short putt or the long putt first. With this procedure, eleven participants did the long putt first while nine participants did the short putt first. If the participant chose the piece of paper labeled "short", he would then perform the experiment in the following order: short baseline, long baseline, short experimental, and long experimental. If the participant chose the long putt first, he would perform the experiment as follows: long baseline, short baseline, long experimental, and short experimental. Baseline performance was established on the primary task (putting) by allowing participants to warm-up by hitting 6 practice putts that were not scored followed by 6 putts that were scored. Putts were scored by measuring the distance from the edge of the cup to the center of the golf ball to the nearest quarter inch after each trial. A putt that was made was counted as 0 inches. A putt that went off of the putting surface was counted as a performance error and later recalculated by scoring it as two standard deviations from the individual's mean score. The average score of these baseline trials served as a baseline performance score. An average was calculated for the short putt and the long putt separately. Baseline performance on the primary task was monitored because participants' performance on the primary task should not degrade when switching from single-task to dual-task conditions. If there is a statistically significant difference in performance under single-task and dual-task conditions, this suggests that the participant reprioritized the tasks (Abernathy, 1988). If this occurs, it becomes difficult to determine whether changes in secondary task performance are a result of the attentional demands of the primary task or a consequence of the reprioritization.

After completion of these baseline putting trials from both 6 feet and 12 feet, participants established a baseline performance on the secondary task (verbal response). Participants performed 12 trials in which they verbally responded to an auditory tone by saying the word "ball" as quickly as possible. The appropriate volume of these tones was selected based on the need for the participants to hear the tone while not being startled. This volume level was established during pilot testing and was not adjusted for the duration of the study. For the duration of these trials, participants took their putting stance and addressed the golf ball as if they were going to putt, and the experimenter generated the auditory tones by breaking the beam of light being emitted from the photocell from behind a partition so that participants would not be able to see movement and potentially anticipate the auditory tone. The average reaction time of these baseline trials served as a baseline reaction time score.

In the next stage of the study, participants performed under dual-task conditions, in which they hit the same putts (the primary task) while monitoring the auditory tone and responding verbally (the secondary task). Participants were instructed to focus primarily on putting and were told that the primary goal was to make as many putts as possible. Putting performance was monitored during the experimental trials using the same methods as in the baseline trials. Catch trials, in which there was no auditory stimulus during randomly-selected dual-task trials, were used to prevent anticipatory effects as participants became accustomed to hearing the auditory tone. The experimenter informed participants that such trials would be randomly included. Since there was no auditory tone during these trials, only putting performance data was collected during catch trials.

Participants were asked to perform a total of 54 experimental trials for data collection at each distance (for a total of 108 experimental trials). Of the 54 trials at each location, 12 trials were presented relative to each of the three probe positions and 18 catch trials were performed. This number of experimental trials was chosen based on requirements for sufficient data collection and subjective feedback about fatigue from pilot subjects. The number of catch trials was chosen based on the recommendation by Abernathy (1988) that at least 33% of the total experimental trials should be catch trials. The order for the presentation of probe position trials and catch trials was chosen using a random order generator; this presentation order was used for all participants on both the short putt and the long putt (see Appendix B). The lack of a response to the auditory tone or a response to a catch trial was recorded as a reaction time error on the data collection sheet.

The golfers in this study were allowed to place the ball on the distance marker and use a pre-shot routine prior to each putt. During this pre-shot routine, the photocells and the software operating them were not active. Once the golfer placed his putter behind the golf ball, the equipment was then activated to generate the auditory tone. The photocells were placed uniquely by the experimenter for each participant based on the distance the putter head was placed behind the golf ball and the length of the putting stroke. This action had to be performed at both the beginning of the short experimental trials and the long experimental trials because of changes in the length of the putting stroke. For consistency in the administration of the auditory tone, the photocells were not moved for the remainder of the trials once they were properly placed.

Performance on the putting task was measured by calculating the average distance from the cup. A separate average was maintained for short and long putts. Since there were 12 golf balls, the experiment was performed in trial blocks of 12 putts, and participants were given the option to take a break after each trial block.

Data Reduction

Data were collected in this study by recording participants' reaction times at the three established probe positions and by recording performance on the putting task. The auditory software Audacity 1.3 was employed to identify the moment when the auditory tone began and verbal response to the tone began. As in Price et al. (2009), reaction time is defined for the purposes of this study as the time from the start of the auditory tone to when the verbal response reaches an amplitude of 0.1 dB. The reaction times of all participants were recorded in this way in order to ensure a standardized measure of reaction time and limit the impact of subjective judgments regarding when the sound recording indicated that the word "ball" was verbalized. Audio files from the digital voice recorder were loaded onto the computer and audio waveforms were then analyzed in Audacity 1.3 to determine reaction time. The beginning of the auditory tone and the beginning of the verbal response were identified by a visual and auditory surge in activity on the waveform file. Within the Audacity software program, the envelope editing tool was used to mark the point at which the waveform reached 0.1 decibels. By zooming in on the waveform, reaction time was measured with a resolution of 0.0001 seconds. The time at which the auditory stimulus began was then subtracted from the time at which the verbal response began in order to achieve a reaction time for each trial. The investigator entered this information for baseline and experimental trials into a Microsoft Excel spreadsheet and reaction time for each trial was calculated. Additionally, the spreadsheet column for trial number and probe position remained hidden during data reduction so that the experimenter would not be aware of which probe position was being analyzed.

Data Analysis

In the dual-task paradigm, attentional demand cannot be accurately assessed unless the primary task is given the most attentional weight. If participants reprioritize the tasks, conclusions about attentional demand can no longer be drawn (Abernathy, 1988). To ensure that primary task performance was maintained from baseline to experimental trials, a two-way repeated-measures analysis of variance (ANOVA) with task difficulty (2) and trial block (baseline, PP1, PP2, PP3, catch) as the independent variables was performed to assess primary task performance. For this analysis, performance (distance from the cup) was the dependent variable. For the purposes of this comparison, the last 6 of the 12 baseline trials were used due to a leveling off of performance around trial 6 or 7 (see Figure 1). If significant effects for trial block or trial block by task difficulty were observed, follow-up analyses were conducted to clarify the nature of these effects.

Performance error data was described relative to the various trial blocks and was statistically examined using a task difficulty (2) by trial block (baseline, PP1, PP2, PP3, catch) repeated measures ANOVA.

To examine the time course of attention, reaction time data was examined using a two-way ANOVA with repeated measures on both factors: task difficulty (2) and probe position (3). For this analysis, reaction time was the dependent variable, and the average reaction time was used since the auditory tone was sounded several times at each probe position.

Reaction time error data were described relative to the probe positions and were statistically examined using a task difficulty (2) by probe position (PP1, PP2, PP3) repeated measures ANOVA.

Additionally, participants were divided into handicap groups based on their golf handicap. Lower- handicap golfers (those possessing a handicap of 9 or better, N = 9) and higher-handicap golfers (those possessing a handicap of 10 or worse, N = 11) were compared. This division was chosen based on the average handicap (-9.31) and the fact that this division provided each group with a similar number of participants. Since there was a wide range of handicaps represented in this study, this analysis was performed in order to examine the time course of attention separately for the two groups. To ensure that putting was maintained as the primary task, a two-way repeated-measures analysis of variance (ANOVA) with task difficulty (2) and trial block (baseline, PP1, PP2, PP3, catch) as the independent variables was performed to assess primary task performance. If significant effects for trial block or trial block by task difficulty were observed, follow-up analyses were conducted to clarify the nature of these effects.

Finally, using a tertiary split, the participants in this study were divided based on overall putting performance. Average performers were discarded from this analysis (N=6) and high performers (N=7) were then compared to low performers (N=7). This analysis was performed in order to determine if there were any differences in attentional patterns (reaction time) for high performers and low performers. To ensure that putting was maintained as the primary task, a two-way repeated-measures analysis of variance (ANOVA) with task difficulty (2) and trial block (baseline, PP1, PP2, PP3, catch) as the independent variables was performed to assess primary task performance. If significant effects for trial block or trial block by task difficulty were observed, follow-up analyses were conducted to clarify the nature of these effects. For all ANOVAs, significant interactions were followed up with univariate ANOVAs and any significant main effects were followed up with dependent samples t-tests to further explore the results.

CHAPTER IV

RESULTS

Inter-Observer Reliability

A secondary observer analyzed reaction time data for one participant in the same manner as the principle investigator in order to establish reliability of data measurement. A correlation showed that the reaction time measured between the two observers were highly reliable (r=0.92), suggesting that the standardization guidelines for measuring and entering reaction time, and data that were entered could be reliably reproduced by other observers.

Putting Performance

Putting performance as a function of trial block and task difficulty is displayed in Figure 2 and descriptive data is presented in Table 3. A 2 x 5 repeated-measures ANOVA for putting performance indicated that there was a main effect for performance based on task difficulty, F (1,19) = 15.525, $p < .05$, $\eta^2 = .45$, such that performance was better on the short putt (M = 3.66, SD = 8.02) than the long putt (M = 5.62, SD = 9.05). Based on this analysis, there was also a main effect for probe position, F (3,17) = 6.044, $p < .05$, $\eta^2 = .516$. Finally, there was a trend for a distance by probe position interaction, F (3,17) = 2.716, $p = .077$, $\eta^2 = .324$. Given the importance of ensuring that performance of the dual task does not affect putting performance, that the main effect for probe position was significant, and that the interaction was nearly significant, further analyses were conducted for each distance to further examine this effect.

For the short putt, a dependent samples t-test showed that there were no significant differences when comparing baseline performance to experimental performance, t (19) = -.205, $p > .05$, two-tailed. Additionally, repeated-measures analysis showed that there was no significant difference between putting performance when comparing performance across probe positions during the experimental trials, F (3,16) = .476, $p > .05$, $\eta^2 = .082$. These findings suggest that participants were able to keep the short putt as the primary task and maintain putting performance under dual-task conditions.

For the long putt, a paired samples t-test showed that there were no significant differences when comparing baseline performance to experimental performance, t (19) = .297, $p > .05$. However, repeated-measures analysis showed that there was a significant difference between putting performance as a function of probe position, F (3,16) = 5.658, $p < .05$, $\eta^2 = .515$. This finding suggests that participants reprioritized the primary and secondary tasks because performance changed across probe positions. Table 3 shows the mean and standard deviation for each condition. Paired-samples t-tests of performance on the long putt further revealed that significant differences in performance could be found between the following probe positions: PP 1 and PP 2, t (19) = 2.835, $p < .05$, PP 1 and PP 3, t (19) = 4.016, $p < .05$, and PP 1 and catch trials, t (19) = 4.156, $p < .05$. Performance at PP1 was significantly worse than performance at either of the other probe positions or during the catch trials. Twelve out of twenty participants experienced a performance decrement at PP 1 when compared with other probe positions.

Performance Errors

A performance error was defined for the purposes of this study as any putt that went off of the putting surface. Performance errors were not counted during practice trials. After practice trials were completed, the number of short baseline performance errors ranged from 0-2. However, 18 out of 20 participants had 0 performance errors for short baseline trials. The number of long baseline performance errors ranged from 0-1. However, 16 out of 20 participants had 0 performance errors for long baseline trials.

For experimental trials, a 2 x 5 repeated-measures ANOVA indicated that there was a main effect for putting errors based on distance, F (1,19) = 14.615, p <.05, η^2 = .435, indicating that significantly more performance errors occurred during the long putt (M = .260, SD = .495) when compared to the short putt (M = .06, SD = .232). Based on this analysis, there was also a main effect for putting errors by trial block, F (4,16) = 3.485, p < .05, η^2 = .466, such that significantly more performance errors occurred during PP 1 trials than during other trial blocks. Finally, there was a significant interaction for distance by trial block, F (4,16) = 3.137, p < .05, η^2 = .440. Figure 2 shows that, overall, more performance errors occurred during the long putt but these errors were increased at PP 1.

Reaction Time

Reaction time as a function of trial block and task difficulty is displayed in Figure 3 and means and standard deviation are presented in Table 4. A 2 x 3 repeated-measures

ANOVA for reaction time indicated that there was a main effect for reaction time based on distance, F (1,19) = 12.194, $p < .05$, $\eta^2 = .405$. Overall reaction time was significantly higher for the long putt condition (M = .423, SD = .130) when compared with the short putt condition (M = .392, SD = .110). There was no main effect for probe position, F (2, 18) = .530, $p > .05$, $\eta^2 = .056$. Finally, there was no interaction for distance and probe position, F (2, 18) = 2.079, $p > .05$, $\eta^2 = .188$.

Reaction Time Errors

A reaction time error was defined as a response to a catch trial or no response to an experimental tone. Reaction time errors at PP 1 ranged from 0-3, and 12 out of 20 participants had no reaction time errors at PP 1. Reaction time errors at PP 2 ranged from 0-2 and 15 out of 20 participants had no reaction time errors at PP 2. Reaction time errors at PP 3 ranged from 0-1 and 14 out of 20 participants had no reaction time errors at PP 3. Reaction time errors on catch trials ranged from 0-1 and 19 out of 20 participants had no reaction time errors on catch trials.

For experimental trials, a 2 x 4 repeated-measures ANOVA indicated that there was no main effect for putting errors based on distance, F (1,19) = .856, $p > .05$, $\eta^2 = .043$. Based on this analysis, the main effect for putting errors by probe position was non-significant, F (3,17) = 3.021, $p > .05$, $\eta^2 = .348$. Finally, there was no interaction for distance by probe position, F (3,17) = .028, $p > .05$, $\eta^2 = .005$.

Between-Subjects Factor: Handicap

For the high-handicap group, a 2 x 5 repeated-measures ANOVA showed that there were significant differences in putting performance by task difficulty, F (1,10) =

17.902, $p < .05$, $\eta^2 = .642$. Performance was better for the short putt (*M* = 3.93, *SD* = 4.07) than for the long putt (*M* = 6.56, *SD* = 3.24). There were also significant differences in putting performance by probe position, F (4,7) = 4.403, $p < .05$, $\eta^2 = .716$. Dependent samples t-tests indicated that there were no significant differences in performance on the short putt when comparing probe positions, but there were significant differences in performance on the long putt when comparing probe positions. Performance was significantly, $t(10) = 2.375$, p < .05, better for PP 2 (*M* = 6.96, *SD* = 2.87) than PP 1 (*M* = 9.05, *SD* = 3.23)., and performance was significantly, t(10) = 3.108, p < .05, better for PP 3 (*M* = 6.96, *SD* = 2.87) than PP 1. Additionally, performance was significantly, t(10) = 3.604, p < .05, better for catch trials (*M* = 5.26, *SD* = 2.87) when compared with PP 1, and performance was significantly, t(10) = 2.678, p < .05, better for catch trials when compared with PP 2. There was no significant interaction between task difficulty and probe position, F (4,7) = .866, $p > .05$, $\eta^2 = .331$.

For the low-handicap group, a 2 x 5 repeated-measures ANOVA showed that there were no significant differences in putting performance by task difficulty, F (1,8) = 2.098, $p > .05$, $\eta^2 = .208$. There were also no significant differences in putting performance by probe position, F (3,6) = 1.722, $p > .05$, $\eta^2 = .579$. There was no significant interaction between task difficulty and probe position, F (4,5) = 2.465, $p > .05$, $\eta^2 = .663$.

Since there were no significant differences in putting performance for the low-handicap group, an additional two-way ANOVA was performed to examine reaction time for this group. Results indicated that there was a significant difference in reaction time by task difficulty, *F* (1,8) = 7.806, $p < .05$, $\eta^2 = .494$, such that reaction times were higher for the long putt condition (*M* =.431 , *SD* = .089) than the short putt condition (*M* = .397, *SD* =.076). However, there were no significant differences in reaction time by probe position, *F* (2,7) = 1.474, $p > .05$, $\eta^2 = .296$, nor was there a significant interaction between task difficulty and probe position, *F* (2,7) = 2.114, $p > .05$, $\eta^2 = .377$.

Between-Subjects Factor: Performance Level

For the high-performance group, a 2 x 5 repeated-measures ANOVA showed that there were significant differences in putting performance by task difficulty, *F* (1,6) = 56.786, $p < .05$, $\eta^2 = .904$. Performance was better for the short putt (*M* = 1.00, *SD* = 1.33) than for the long putt (*M* = 3.67, *SD* = 2.28). However, there were no significant differences in putting performance by probe position, *F* (3,4) = 2.087, $p > .05$, $\eta^2 = .736$. There was no significant interaction between task difficulty and probe position, *F* (3,4) = 1.620, $p > .05$, $\eta^2 = .684$.

For the low-performance group, a 2 x 5 repeated-measures ANOVA showed that there were no significant differences in putting performance by task difficulty, *F* (1,6) = 2.478, $p > .05$, $\eta^2 = .292$. However, there were significant differences in putting performance by probe position, *F* (3,4) = 634.984, $p < .05$, $\eta^2 = .999$. Dependent samples t-tests indicated that there were no significant differences in performance on the short putt when comparing probe positions, but there were significant differences in performance on the long putt when comparing probe positions. Performance was significantly, $t(6) = 3.906$, $p < .05$, better for PP 2 (*M* = 7.65, *SD* = 3.16) than PP 1 (*M* = 11.87, *SD* = 1.70) and performance was significantly, $t(6) = 3.109$, $p < .05$, better at PP 3

(*M* = 8.00, *SD* = 2.52) than PP 1. Performance was also significantly, t(6) = 5.164, p < .05, better on catch trials (*M* = 6.06, *SD* = 2.73) than PP 1. There was no significant interaction between task difficulty and probe position, *F* (3,4) = 1.140, *p* > .05, η^2 = .603.

Since there were no significant differences in putting performance for the high-performance group as a function of probe position, an additional two-way ANOVA was performed to examine reaction time for this group. Results indicated that there was a significant difference in reaction time by task difficulty, *F* (1,6) = 13.229, *p* < .05, η^2 = .688, such that reaction times were higher for the long putt condition (*M* =.434, *SD* = .111*)* than the short putt condition (*M* =.396, *SD* =.094). However, there were no significant differences in reaction time by probe position, *F* (2,5) = 3.809, *p* > .05, η^2 = .604, nor was there a significant interaction between task difficulty and probe position, *F* (2,5) = 4.702, *p* > .05, η^2 = .653.

CHAPTER V

DISCUSSION

The capacity theory of attention suggests that an individual has a fixed, limited pool of attentional resources that may be allocated freely between multiple tasks. If an individual attempts multiple tasks or a difficult task, more attentional resources are required than when one task or a simple task is attempted. Consequently, since this pool of resources is limited, performance will suffer if the maximum capacity of attentional resources is exceeded. When the dual-task paradigm is used to assess attentional resources, a participant is asked to perform a primary task while performing a less-demanding secondary task that acts as the mechanism through which attentional demand is assessed on the primary task. When using the dual-task paradigm, it is important for the participant to maintain primary task performance from baseline to experimental conditions so that attention may accurately be assessed. If the participant's performance level changes from baseline to experimental conditions or across probe positions, it is possible that the participant has reprioritized the tasks and attention may no longer be accurately assessed.

Putting Performance

Overall, there were no statistically significant differences between average baseline (single-task) putting performance and average experimental (dual-task) putting performance (See Figure 4). However, while participants were able to maintain performance across probe positions for the short putt, they were unable to do so for the long putt.

Participants displayed a trend on both the short putt and the long putt to perform better (i.e., reduce average distance to the cup) as the reaction time probes occurred later in the putting stroke. While this trend was non-significant for the short putt, differences in performance across probe positions were significant for the long putt. In addition, there were significantly more performance errors on the long putt when compared with the short putt, and performance errors occurred most often at PP 1 (See Figure 5). As a result of these findings, attentional demand cannot be accurately assessed for the long putt because it is likely that participants either reprioritized the primary and secondary task or found the long putt to be too difficult to maintain a consistent level of performance while also attempting to respond to the reaction time probe.

Although the fact that performance was impacted by probe positions limits our ability to interpret the reaction time data as an indicator of the attentional demands of the task, the performance data and error data as a function of probe position may provide insights into the requirements for execution of the putting task. In particular, the trend for performance to improve as probe position becomes increasingly late is likely due to the distracting nature of the auditory tone to a golfer. Since golf shots are typically taken during silence for the purpose of concentration, an auditory tone may disrupt a golfer's performance, regardless of skill level. However, late probe positions give the golfer less time to be distracted by the beep and, therefore, seem to result in less faulty changes in the putting stroke. Additionally, the individual relies on sensory feedback to adjust the putting stroke during early probe positions, while motor commands and subsequent adjustments have largely been executed during late probe positions. Therefore, an auditory tone administered during early probe positions may disrupt the putting stroke.

In the current study, the performance of experienced golfers under a single-task condition that was not skill-focused was compared with performance under a dual-task condition. Previous research has shown that expert putters tend to perform better under dual-task conditions rather than a skill-focused single-task condition and this has been attributed to the emergence of more automatic modes of processing under dual-task conditions (Beilock et al., 2002). Although the single-task condition of the present study was not designed to have participants be skill-focused as in the Beilock et al. (2002) study, the dual-task condition of this study was very similar to the dual-task condition in the aforementioned study. In Beilock et al., participants listened to auditory tones and responded by saying “tone” as quickly as possible; however, these responses were not recorded and the tones were intended to be a distraction. The results of the Beilock et al. study indicated that participants improved significantly from a skill-focused condition to a dual-task condition. However, in the present study there were no significant differences in performance when comparing single-task and dual-task conditions. Therefore, the finding of the present study suggests that a performance decrement (as could be created by using a skill-focused condition) is necessary to produce significant differences in performance when comparing single-task conditions to dual-task conditions.

As stated previously, it is suggested in Beilock et al. (2002) that the dual-task condition produces an improvement in putting performance because it enhances the participant's use of automatic processing. However, the results of the present study suggest that the auditory tone used in the dual-task paradigm may hurt or help performance as a function of timing. Results indicate that performance at PP 1 (Initiation) is significantly worse than performance at other probe positions. This statement is not only true when PP 1 is compared with PP 2 and PP 3, but also when PP 1 is compared with catch trials that featured no auditory tone. Additionally, more performance errors and reaction time errors occurred at PP1 than at any other probe position. This finding suggests that an auditory tone at the beginning of the putting stroke can actually hinder performance. Therefore, the amount of improvement seen in an experienced putter under dual-task conditions may be a result of the position of the putting stroke during the administration of the auditory tone.

Reaction Time

When compared with baseline reaction time, the increase in reaction time that occurs during probe positions suggests that the putting task selected for this study is attentionally demanding. In support of the original hypothesis of this study, there was a main effect for difficulty level when comparing the long putt (difficult condition) with the short putt (easy condition). Reaction time was significantly higher for the long putt when compared with the short putt, suggesting that the long putt required greater attentional resources than the short putt (see Figure 6). This greater allocation of attentional resources was likely due to the increased task complexity of the longer putt. Since both the short putt and the long putt were on the same putting surface and had a similar line and break, the increased length of long putt made it more attentionally demanding and more difficult to execute. This finding is interesting because the mechanics of the putting stroke remain identical from the short putt to the long putt, while only one parameter - the force applied to the golf ball - changes.

According to the dual-task paradigm, the time course of attention during a given task should indicate where attentional demands are the highest and lowest for various stages of a task. As previously stated, performance differences at each probe position of the long putt prevent an accurate assessment of the time course of attention for this task; however, attentional demand may be accurately assessed for the short putt. In contrast to the expectation that reaction time should be greatest at PP 3 (Pre-contact), the results of this study indicate that there are no significant differences in reaction time at each probe position during the short putt, suggesting that the golf putting stroke for a relatively simple putt requires similar levels of attention throughout the task. While reaction times for the short putt demonstrated an increasing trend from PP 1 to PP 3, these differences were non-significant. Based on the dual-task paradigm, the lack of significant differences in reaction times at these probe positions is due to a consistent attentional demand that is maintained throughout the putting stroke. This consistency in attentional demand may be influenced by the short range of movement in the putting stroke, especially for short putts. A movement with a larger range of motion, such as the full golf swing, might demonstrate larger differences in attentional demand than those present in the current study.

Between-Subjects Factor: Handicap

Since there was a wide range of handicaps for the present study, a binary split was performed at the average handicap of -9.3 to form two groups, including low-handicap participants and high-handicap participants. Results demonstrated that while the high-handicap group (less-skilled golfers) showed significant differences in putting performance based on both task difficulty and probe position, the low-handicap group (more-skilled golfers) showed no such significant differences (See Figures 7 and 8). Both groups performed similarly on the short putt, but the low-handicap golfers performed better on the long putt than the high-handicap golfers. This suggests that the 6-foot putt is not difficult enough to produce a difference in performance based on handicap while the 12-foot putt is difficult enough to produce such a difference. Additionally, in the high-handicap group, there were significant differences for performance by probe position while there were no such significant differences in performance in the low-handicap group. Since the high-handicap group demonstrated changes in performance across probe positions, no assertions about attentional demand can be made. These findings suggest that the high-handicap group may have found the putts selected for this study to be too difficult to maintain primary task performance while the low-handicap group was skilled enough to maintain primary task performance.

Since there were no significant differences in performance as a function of task difficulty, probe position, or their interaction for the low-handicap group, reaction time data was examined for this group. Results indicated that there was a significant difference in reaction time as a function of task difficulty, with the long putt requiring greater attentional demand. Results also indicated that there were no significant differences in reaction time for probe position or for probe position by task difficulty in the low-handicap group, indicating that both putts had similar levels of attentional demand throughout the putting stroke (See Figure 11).

Between-Subjects Factor: Performance Level

Since there was a wide range of performance levels in this study, a tertiary split was performed to separate low performers and high performers. Intermediate performers (N = 6) were excluded from this analysis. Low performers showed no significant differences in performance as a function of distance but did demonstrate significant differences in performance as a function of probe position. In contrast, high performers showed significant differences in performance as a function of distance while showing no significant differences in performance as a function of probe position (See Figures 9 and 10). Since there were differences in performance by trial block in the low-performance group, no additional conclusions about attentional demand may be drawn. However, since there were no differences in performance by trial block in the high-performance group, conclusions about attentional demand may be drawn. The high-performance group showed a slower reaction time for the long putt, indicating that this putt was more attentionally demanding, but there were no differences in reaction time by probe position, indicating that attentional demand remains steady in this group throughout the putting stroke. These findings relative to the high-performance group mirror those of the low handicap group. Finally, it is interesting to note that low performers consistently displayed reaction times that were faster than high performers at all probe positions for both putts (see Figure 12). In conjunction with the performance differences observed for this group, this may suggest that the low performers reprioritized the tasks and paid more attention to the RT task than to the putting task.

Conclusions

While this study used past literature concerning investigations of attentional demand during sport-specific movements using the dual-task paradigm to formulate a sound study, the present study still has weaknesses. Although this study used photocells to detect the movement of the putter and administer the auditory tones at the same probe position each time, the photocells were also not sensitive enough to detect the narrow shaft of the putter. To compensate for this problem, an index card had to be attached to the putter shaft of each participant. During baseline trials, each participant was given a chance to warm-up and perform under single-task conditions with the index card attached. However, the potential impact of the index card on the putting execution itself may impact the generalizability of the results of this study. The ecological validity of this study is also challenged because participants were performing inside the controlled environment of a lab and were putting on a carpeted platform that was created specifically for the purposes of this study. Thus, results may not generalize to putting outdoors.

As stated previously, this study examined a sport-specific movement that involved striking a stationary object with an implement. The unique results involving the time course of attention that were found in this study may be a direct result of the methods employed to execute this movement. Future studies should involve additional sport-specific movements that are similar to a golf putt such as a hockey strike (or a field hockey strike), a croquet strike, or a full golf swing. Studies such as these would determine whether the golf putting stroke has a unique pattern of attentional demand or all movements that involve striking a stationary object for accuracy display a similar pattern. Additionally, future studies should examine differences in task difficulty in order to ascertain the distance at which a putt becomes too difficult to maintain a consistent level of primary task performance. As described in this study, a 6-foot putt was not sufficiently difficult enough to disrupt primary task performance while a 12-foot putt was difficult enough to disrupt primary task performance. There may be a definitive distance in between this range at which primary task performance suffers. A study such as this one may determine the distance at which a golfer perceives a putt to be consistently makeable versus inconsistently makeable. Future studies involving golf and the dual-task paradigm should investigate whether or not it is detrimental to use a response to an auditory tone as the secondary task. Since golf shots are taken during silence, other secondary tasks that are visual or somatosensory in nature may be more effectively employed than an auditory task. Finally, since both the low-handicap group and the high-performance group were able to maintain primary task performance across probe positions, future studies should select golfers of a lower handicap (i.e., less than 10) than those used in the current study.

This study is unique when compared with past literature involving the dual-task paradigm not only because it examines the time course of attention during a putting stroke but also because it demonstrated a consistent level of attentional demand throughout the short putt. Sport-specific studies in past literature have demonstrated declines and peaks in attentional demand throughout a movement. However, the results of this study suggest that the putting stroke is unique because attentional demand remains consistent throughout the motion when participants are performing a relatively easy putt. The results of this study also indicate that experienced golfers, as a group, are unable to maintain primary task performance on a putt of 12 feet due to an increase in task difficulty. A primary reason for this finding may be that the administration of an auditory tone during the initiation of the putting stroke dramatically impacts a golfer's ability to successfully execute the task. The results of this study also support past literature that suggests that a task that is high in difficulty will result in higher reaction times and greater attentional demand when compared with a task that is low in task difficulty.

Furthermore, low-handicap golfers were able to maintain consistent levels of performance under dual-task conditions when compared with high-handicap golfers. Similarly, those golfers who performed in the top third on the putting task were also able to maintain their performance while executing the reaction time task. When examining the attentional demands of the more difficult (longer) putt, both the low-handicap golfers and the better performers maintained a consistent level of attentional demand throughout the putting stroke, thus, supporting the contention that for putts that are viewed as "make-able", attentional demand does not change across probe positions. However, for tasks that are viewed as more difficult (i.e., the long putt for the high handicappers and the poorer performers), the attentional demands of a putt can become high enough that they are not able to perform the reaction time task without compromising their ability to perform the putting task.

REFERENCES

Abernathy, B. (1988). Dual-task methodology and motor skills research: Some applications and methodological restraints. *Journal of Human Movement Studies*, *14*, 101-132.

Abernathy, B., Maxwell, J. P., Masters, R., Kamp, J., and Jackson, R. (2007). In G. Tenenbaum & R. Eklund (Eds.), *Handbook on sport and exercise psychology* (3^{rd} ed., pp. 245-258). Hoboken, NJ: Wiley.

Beilock, S. L., Bertenthal, B. I., McCoy, A. M., & Carr T. H. (2004). Haste does not always make waste: Expertise, direction of attention, and speed versus accuracy in performing sensorimotor skills. *Psychonomic Bulletin and Review*, *11*, 373-379.

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experience performance of sensorimotor skill. *Journal of Experimental Psychology: Applied*, *8*, 6-16.

Bourke, P. A., Duncan, J., & Nimmo-Smith, I. (1996). A general factor in dual-task performance decrement. *The Quarterly Journal of Experimental Psychology*, *49A* (3), 525-545.

Castiello, U. & Umilta, C. (1988). Temporal Dimensions of Mental Effort in Different Sports. *International Journal of Sports Psychology*, 19, 199-210.

Hodges, N. J., Huys, R., & Starkes, J. L. (2007). In G. Tenenbaum & R. Eklund (Eds.), *Handbook on sport and exercise psychology* (3rd ed., pp. 161-178). Hoboken, NJ: Wiley.

James, W. (1890). *The Principles of Psychology*. Cambridge, MA: Harvard University Press.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice-Hall.

Prezuhy, A. M. & Etnier, J. L. (2001). Attentional patterns of horseshoe pitchers at two levels of task difficulty. *Research Quarterly for Exercise and Sport*, *72* (3), 293-298.

Posner, M. I., & Rossman, E. (1965). Effect of size and location of informational transforms upon short-term retention. *Journal of Experimental Psychology*, *70*, 496-505.

Price, J., Gill, D.L., Etnier, J., & Kornatz, K. (2009). Free throw shooting during dual-task performance: Implications for attentional demand and performance. *Research Quarterly for Exercise and Sport*, 80, 718-726

Rose, D. J., & Christina, R. W. (1990). Attention demands of precision pistol shooting as a function of skill level. *Research Quarterly for Exercise and Sport*, *61*, 111-113.

Schmidt, R. A. & Lee, T. D. (2005). *Motor Control and Learning: A Behavioral Emphasis* (4th ed.). Champaign, Illinois: Human Kinetics.

Sibley, B. A. & Etnier, J. L. (2004). Time course of attention and decision making during a volleyball set. *Research Quarterly for Exercise and Sport*, *75* (1), 102-106.

Styles, E. A. (2006). *The Psychology of Attention* (2nd ed.). Hove, England: Psychology Press.

Wulf, G. (2007). *Attention and Motor Skill Learning*. Champaign, Illinois: Human Kinetics.

Young, M. S. & Stanton, N. A. (2007). Miles away: Determining the extent of secondary task interference on simulated driving. *Theoretical Issues in Ergonomics Science, 8* (3), 233-253.

APPENDIX A

TABLES

Table 1. An Explanation of Probe Positions.

Probe Number	Probe Name	Probe Description
1	Initiation	The start of the backswing
2	Mid-Stroke	The peak of the backswing
3	Pre-Contact	The point immediately prior to contact with the golf ball
4	Catch	No tone is sounded – used to minimize anticipatory effects

Table 2. Participant Demographics.

Participant Number	Gender	Age	Handedness	Total Experience (Years)	Handicap	Competitive Experience (Years)
1	Male	20	Right	12	-9	None
2	Male	28	Right	13	-12	None
3	Male	31	Right	16	-10	None
4	Male	24	Right	16	-15	High School - 5
5	Male	25	Right	12	-15	None
6	Male	23	Right	14	-17	None
7	Male	20	Right	15	2.4	High School - 4, College - 2
8	Male	23	Right	10	-16	High School - 3
9	Male	24	Right	10	-16	None
10	Male	24	Right	13	-11	High School - 4
11	Male	25	Right	22	0	High School - 5, College - 2
12	Male	21	Right	9	-6	None
13	Male	62	Right	50	-5.5	High School - 3
14	Male	55	Right	30	-11	None
15	Male	71	Right	15	-15	None
16	Male	68	Right	56	-10	High School - 3
17	Male	50	Right	43	-4	High School - 3
18	Male	58	Right	37	-8	None
19	Male	42	Right	35	1	High School - 4, College - 4
20	Male	23	Right	7	-9	High School - 3

Table 3. A Comparison of Performance for Each Condition.

Condition		Mean		Standard Deviation
Short Baseline		3.5185		3.5984
Short Overall		3.6398		7.9889
Long Baseline		5.9302		4.6196
Long Overall		5.4877		9.0859
PP 1 Overall		5.8316		10.0707
PP 2 Overall		4.6357		9.1588
PP 3 Overall		4.1588		7.5051
Catch Overall		3.9399		7.7228
Short PP 1		4.0719		8.7050
Short PP 2		3.7897		8.6742
Short PP 3		3.3156		7.2020
Short Catch		3.4681		7.5175
Long PP 1		7.5912		11.0122
Long PP 2		5.4816		9.5624
Long PP 3		5.0020		7.7208
Long Catch		4.4117		7.9051

Note: Short = Short Putts; Long = Long Putts; PP = Probe Position; Catch = catch trials.

Table 4. A Comparison of Reaction Times for Each Condition.

Condition	Minimum	Maximum	Mean	Standard Deviation
Baseline	0.1981	0.6038	0.3185	0.0604
Short Putt Overall	0.1721	1.2665	0.3914	0.1122
Long Putt Overall	0.1759	1.2011	0.4238	0.1333
PP 1 Overall	0.1721	1.2011	0.4028	0.1367
PP 2 Overall	0.1762	0.9650	0.4034	0.1070
PP 3 Overall	0.2095	1.2665	0.4166	0.1271
Short PP 1	0.1721	1.2002	0.3832	0.1162
Short PP 2	0.1762	0.7996	0.3937	0.1003
Short PP 3	0.2108	1.2665	0.3973	0.1194
Long PP 1	0.1759	1.2011	0.4224	0.1523
Long PP 2	0.1783	0.9650	0.4131	0.1126
Long PP 3	0.2095	1.1639	0.4359	0.1318

Note: Short = Short Putts; Long = Long Putts; PP = Probe Position; Catch = catch trials.

Table 5. A Comparison of Performance and Reaction Times by Handicap.

	Probe Position	Performance			Reaction Time	
		Mean	SD		Mean	SD
High Handicap	Short PP 1	4.53	4.72		0.38	0.088
	Short PP 2	4.62	4.11		0.39	0.08
	Short PP 3	3.42	3.82		0.39	0.04
	Short Catch	3.42	3.63			
	Long PP 1	9.05	3.23		0.42	0.13
	Long PP 2	6.96	2.87		0.41	0.1
	Long PP 3	5.98	2.98		0.41	0.05
	Long Catch	5.26	2.29			
Low Handicap	Short PP 1	3.51	3.1		0.39	0.09
	Short PP 2	2.78	2.76		0.4	0.07
	Short PP 3	3.19	3.55		0.4	0.06
	Short Catch	3.63	2.51			
	Long PP 1	5.8	3.92		0.42	0.09
	Long PP 2	3.67	2.76		0.41	0.08
	Long PP 3	3.82	2.48		0.46	0.09
	Long Catch	3.37	2.7			

Note: Short = Short Putts; Long = Long Putts; PP = Probe Position; Catch = catch trials.

Table 6. A Comparison of Performance and Reaction Times by Performance Level.

	Probe Position	Performance Mean	Performance SD		Reaction Time Mean	Reaction Time SD
High Performers	Short PP 1	1.18	1.49		0.38	0.11
	Short PP 2	0.53	1.09		0.42	0.10
	Short PP 3	0.48	0.71		0.39	0.07
	Short Catch	1.02	0.90			
	Long PP 1	4.48	2.89		0.41	0.12
	Long PP 2	3.05	2.19		0.43	0.13
	Long PP 3	2.74	0.68		0.45	0.09
	Long Catch	2.85	1.46			
Low Performers	Short PP 1	7.85	3.55		0.36	0.05
	Short PP 2	6.67	3.63		0.37	0.04
	Short PP 3	6.22	3.82		0.39	0.03
	Short Catch	6.18	3.04			
	Long PP 1	11.87	1.70		0.36	0.05
	Long PP 2	7.65	3.17		0.37	0.05
	Long PP 3	8.00	2.52		0.41	0.08
	Long Catch	6.06	2.73			

Note: Short = Short Putts; Long = Long Putts; PP = Probe Position; Catch = catch trials.

APPENDIX B

FIGURES

Figure 1. Mean Baseline Performance on the Long Putt by Trial.

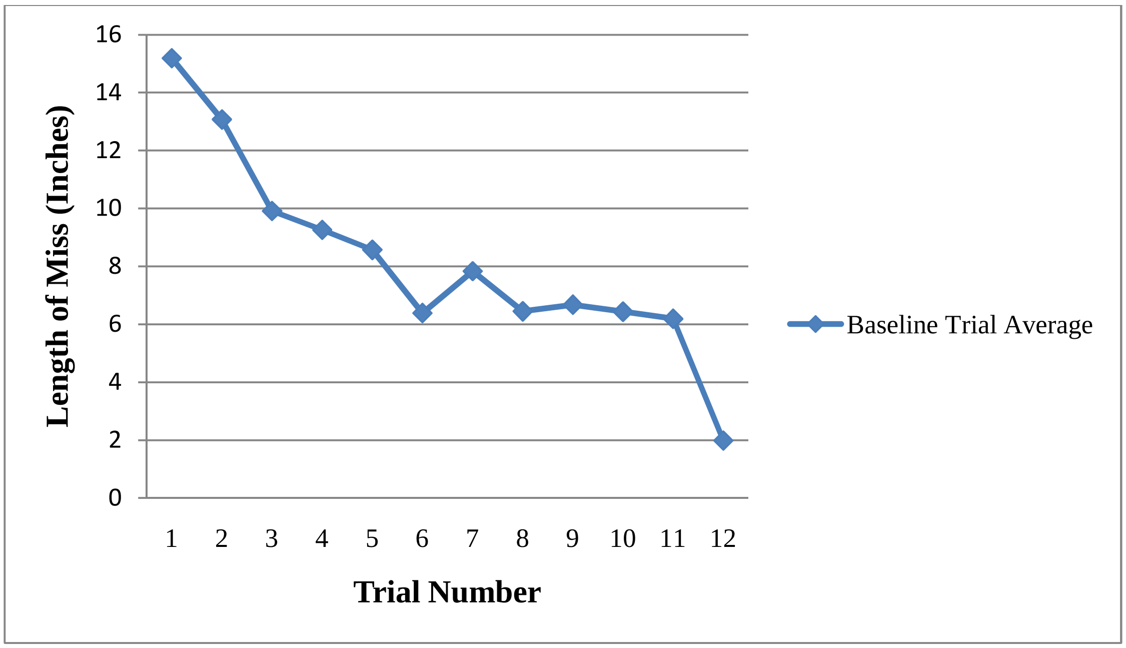


Figure 2. Mean Performance by Trial Block.

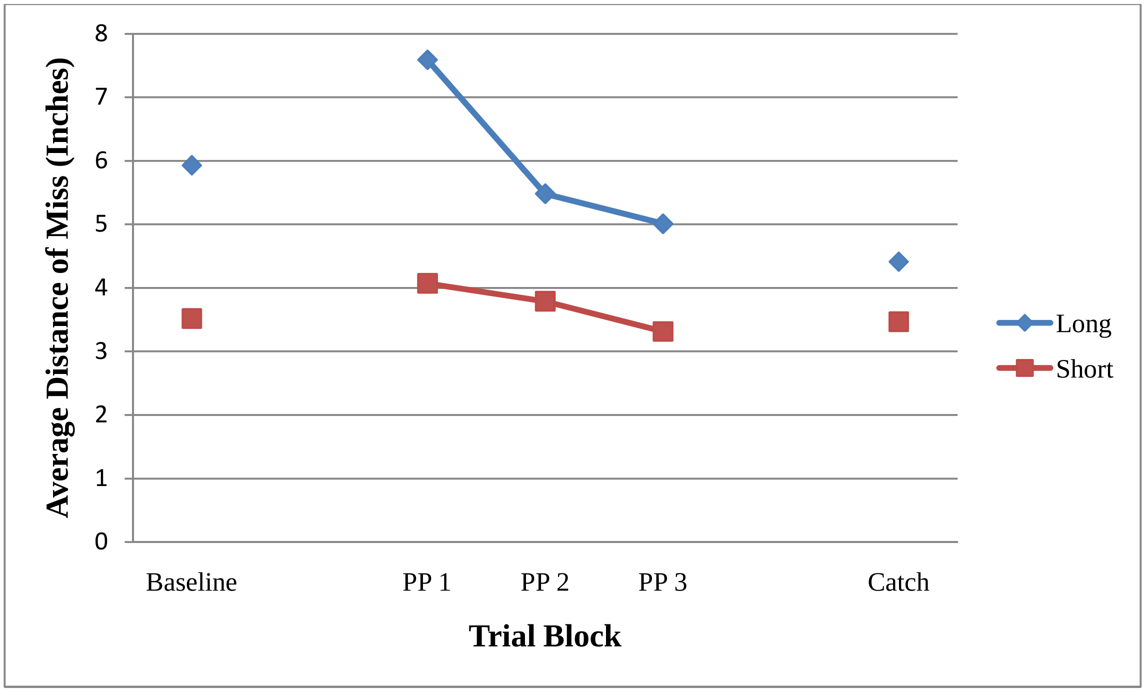


Figure 3. Mean Reaction Time by Probe Position.

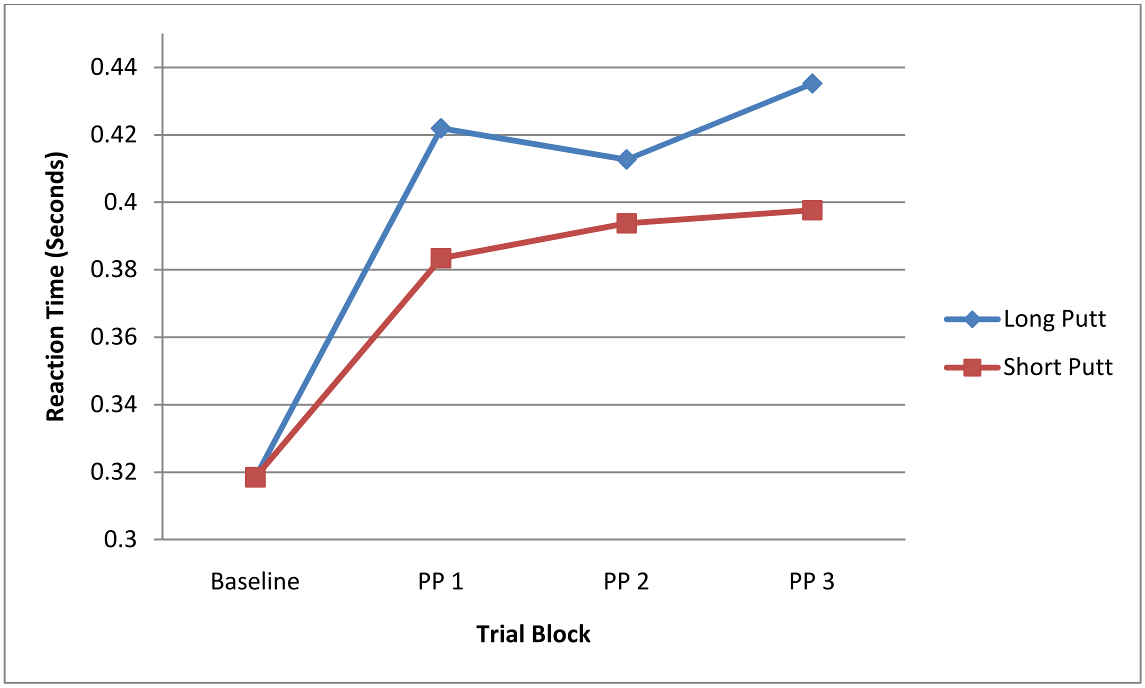


Figure 4. Mean Performance by Condition.

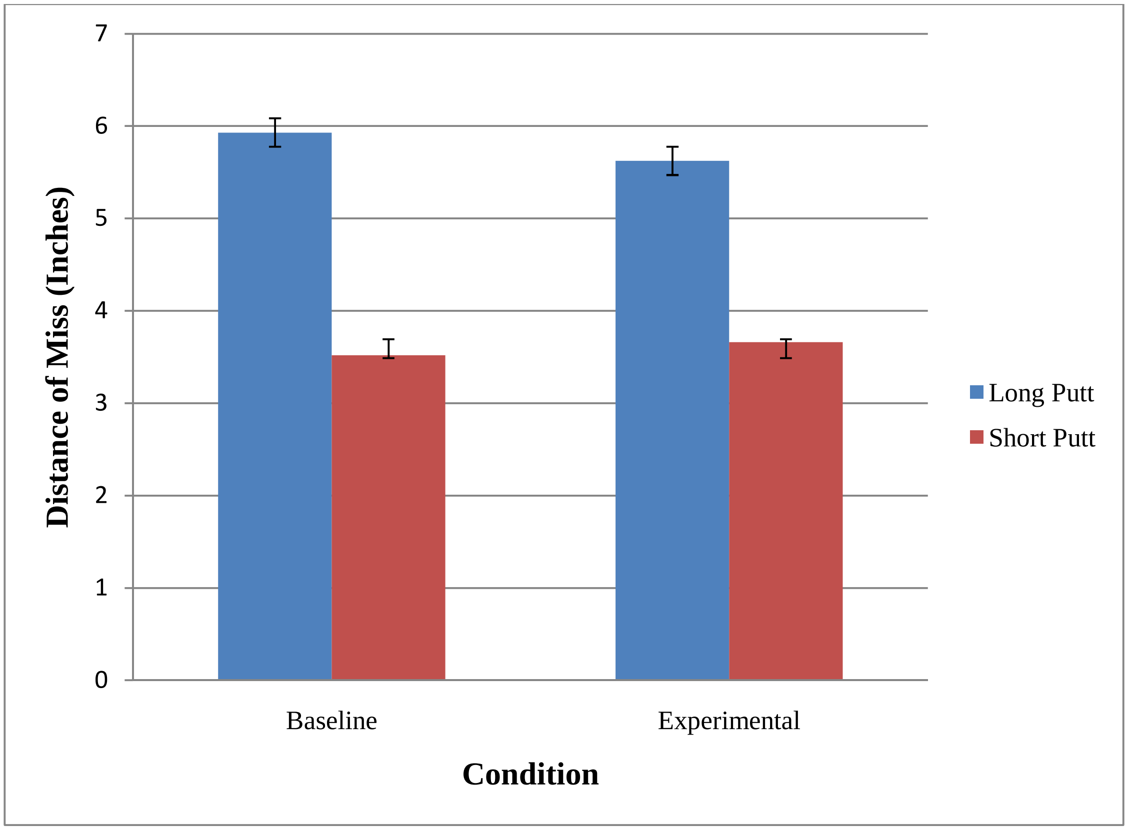


Figure 5. Performance Errors by Trial Block and Task Difficulty.

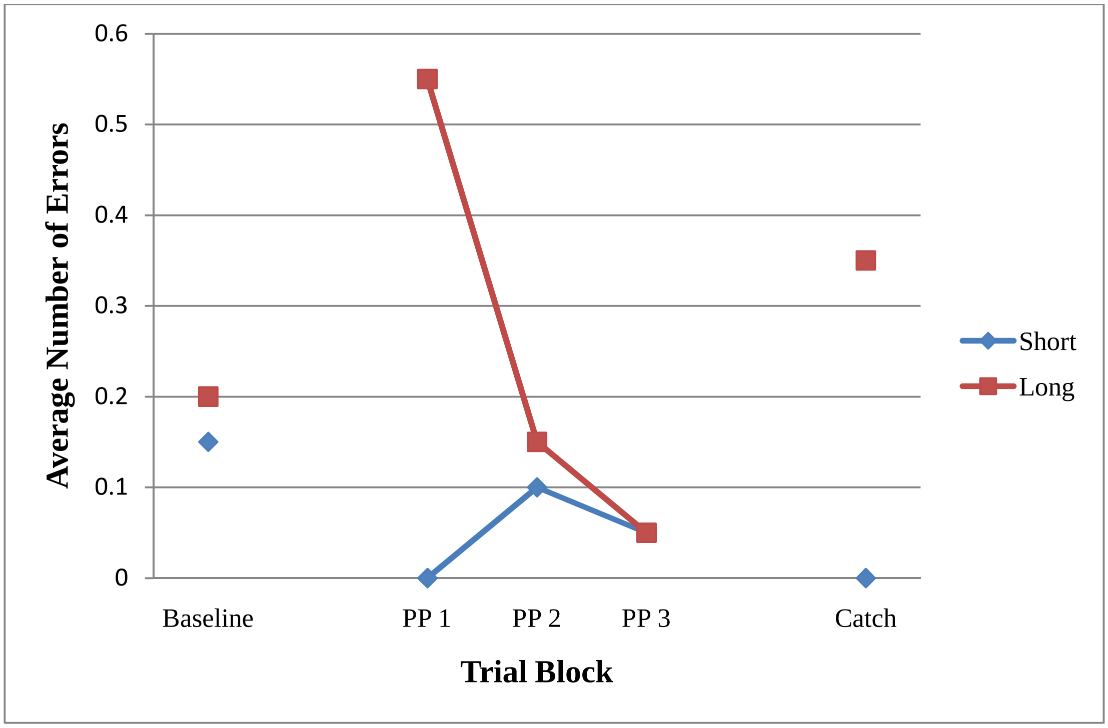


Figure 6. Mean Reaction Time by Condition.

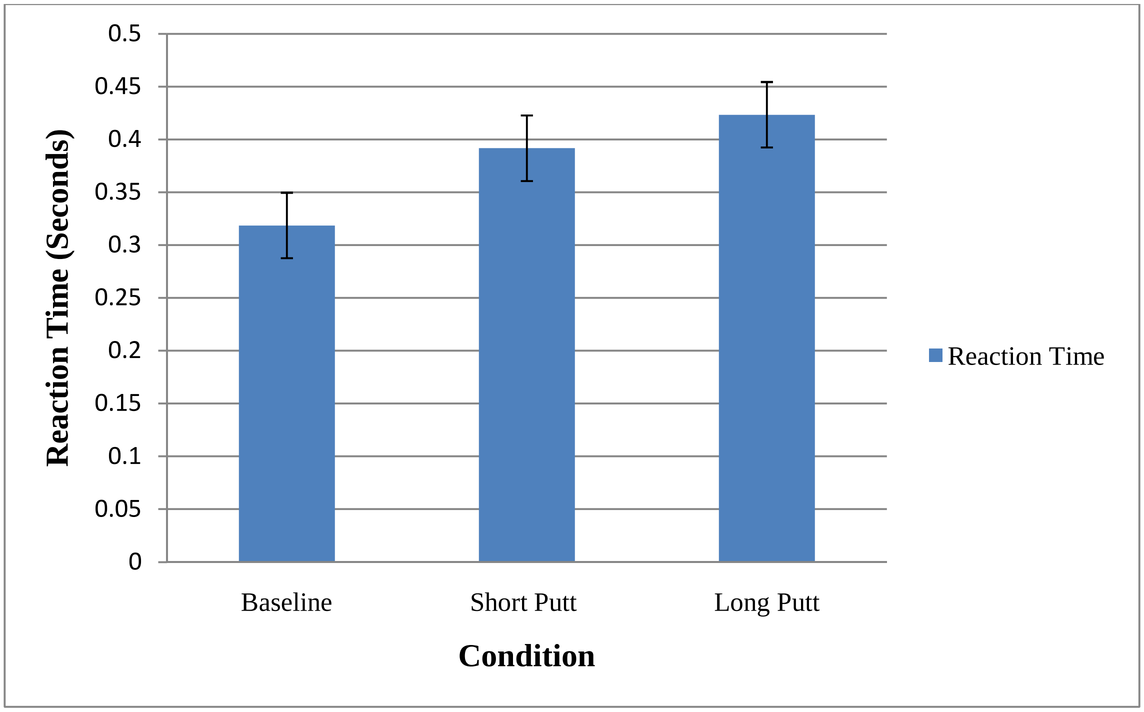


Figure 7. Average Performance on the Long Putt by Handicap Level.

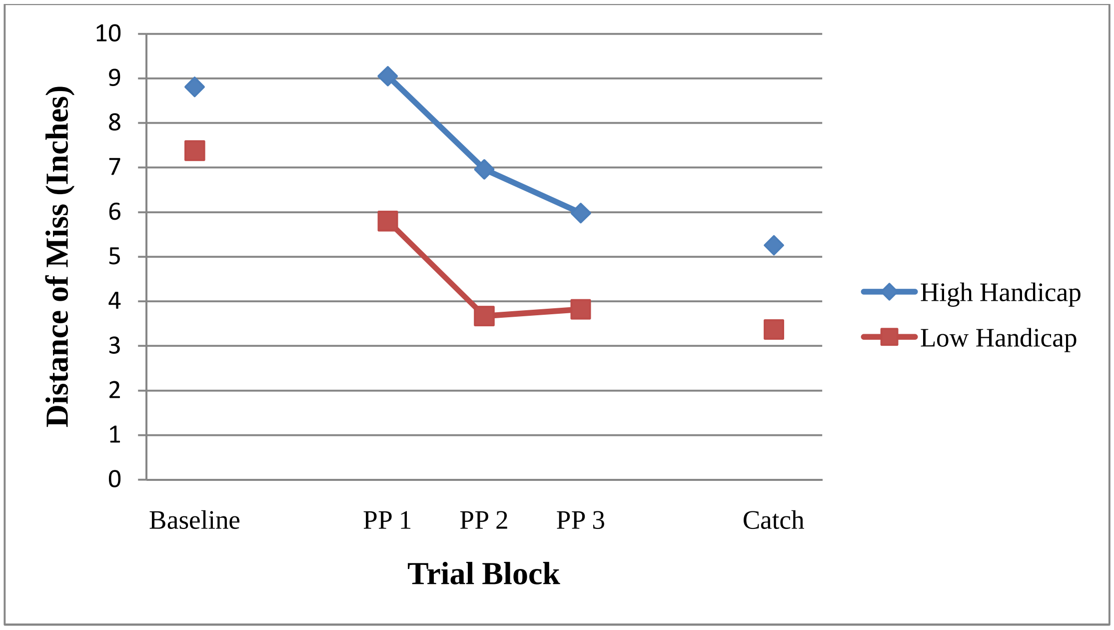


Figure 8. Average Performance on the Short Putt by Handicap Level.

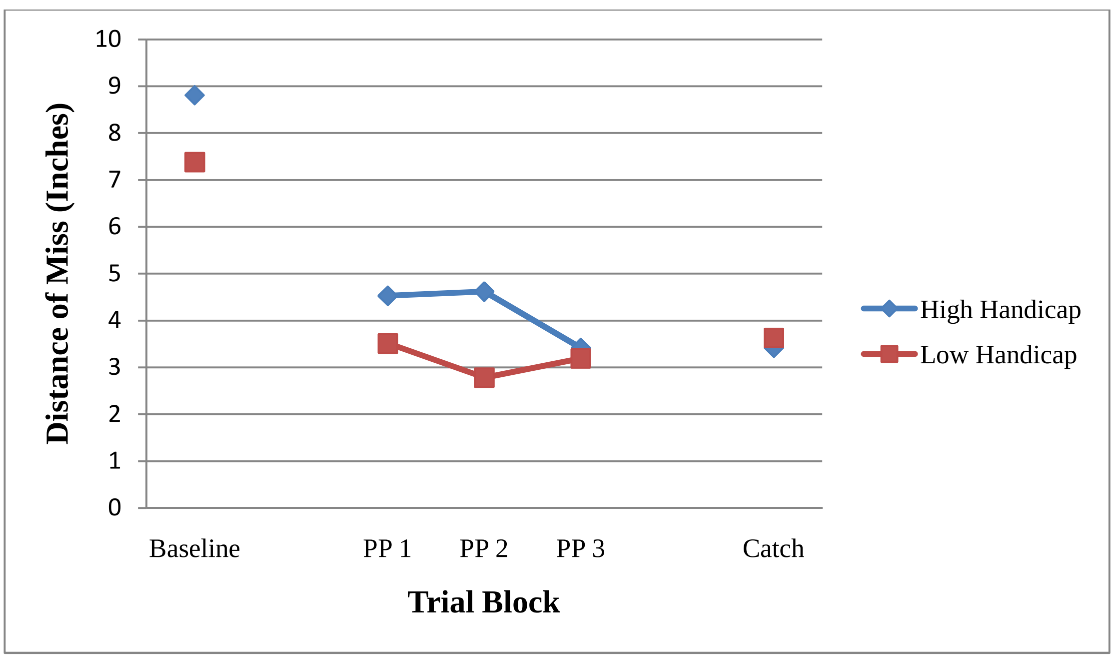


Figure 9. Average Performance on the Long Putt by Performance Level.

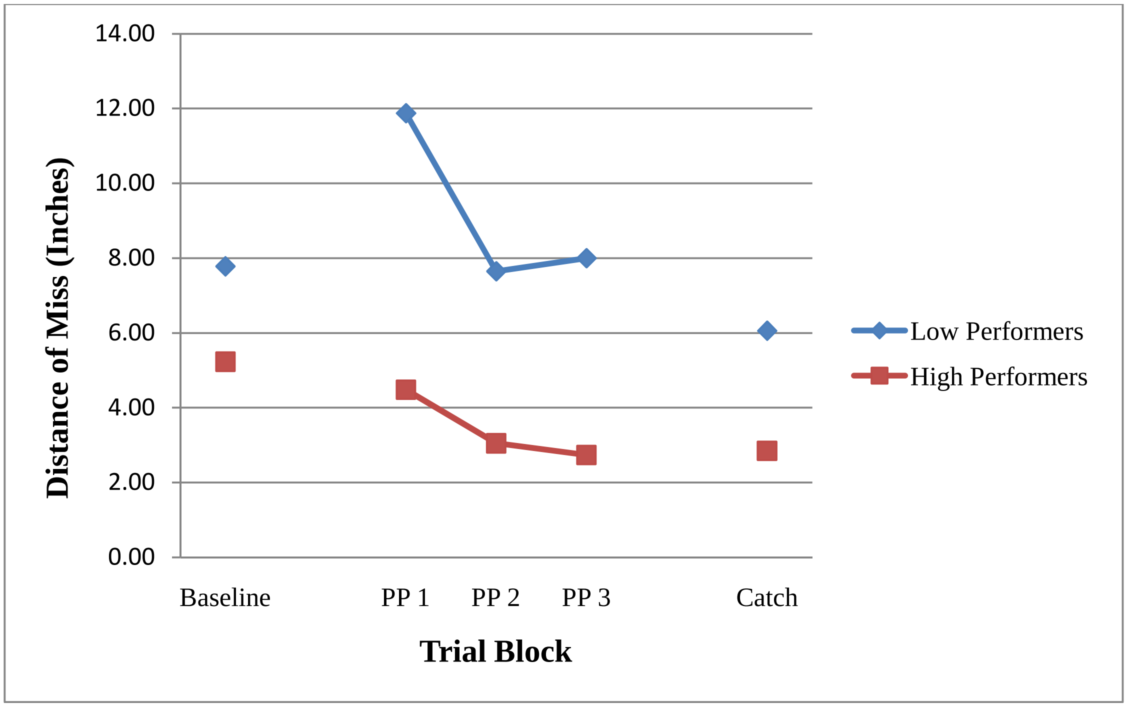


Figure 10. Average Performance on the Short Putt by Performance Level.

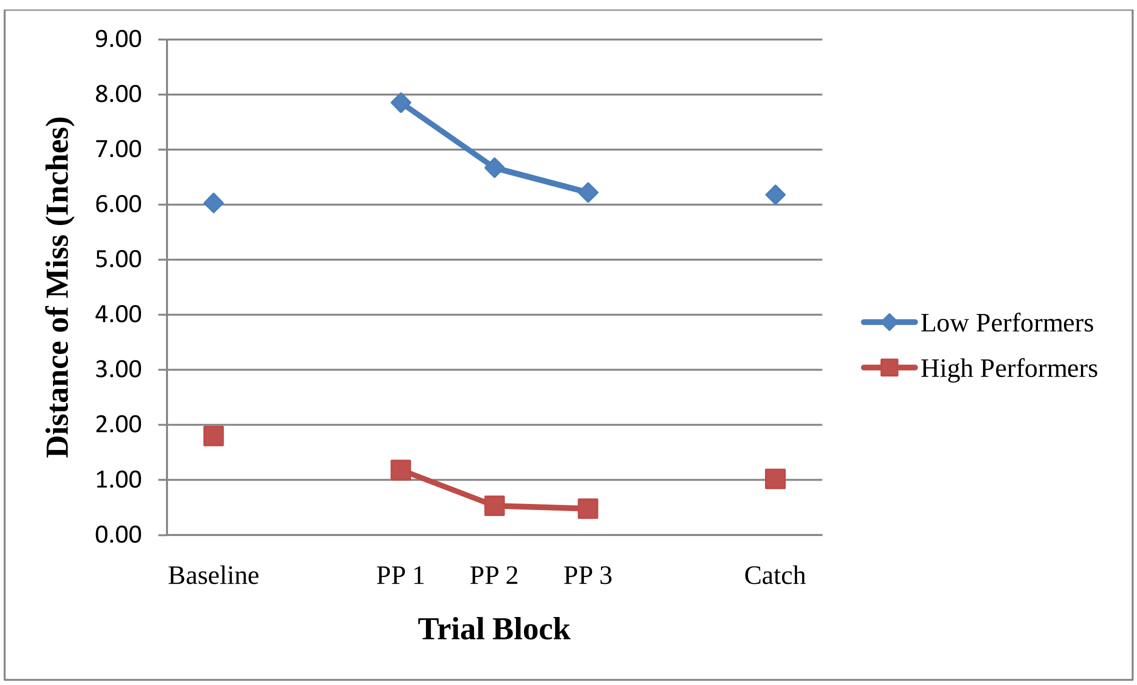


Figure 11. Reaction Times across Probe Positions by Handicap Level

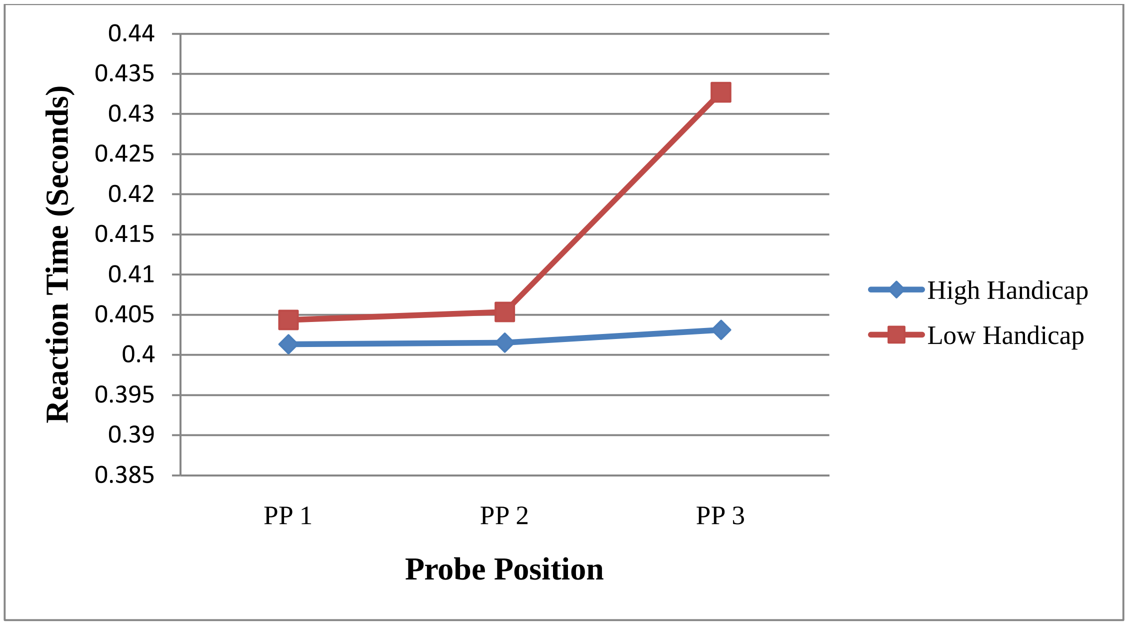
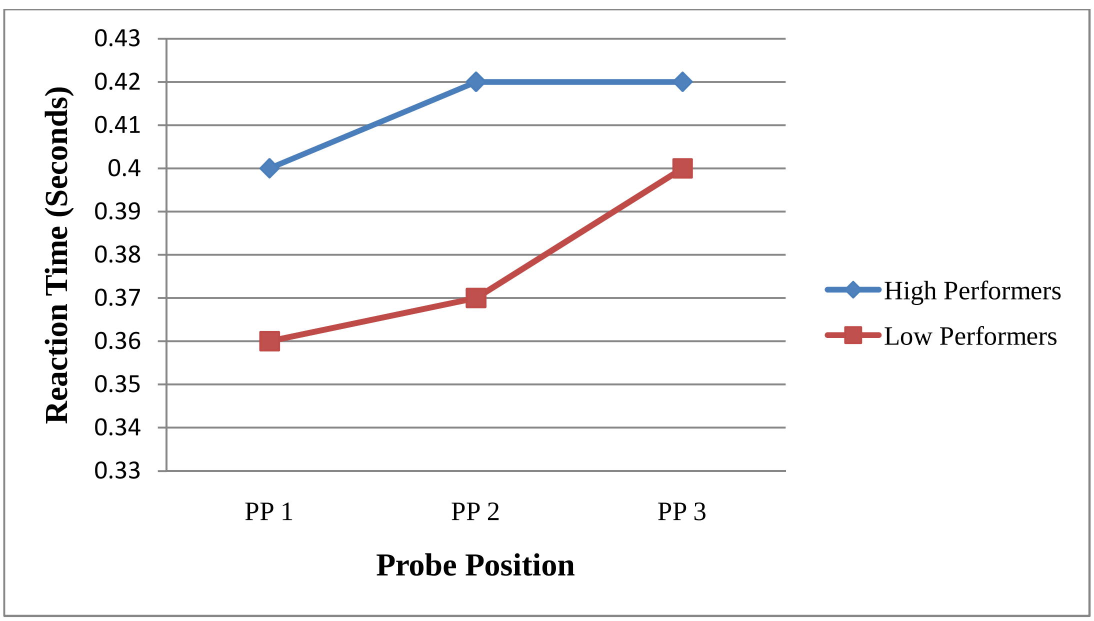


Figure 12. Reaction Times across Probe Positions by Performance Level.



APPENDIX C

DEMOGRAPHIC QUESTIONNAIRE

ID ______

1. Gender _______
2. Age __________
3. What is your current occupation? ______________________________
4. Do you play golf right-handed or left-handed? ________________
5. Did you play golf competitively in high school? _____If so, how many years? ______
6. How many total years have you been playing golf? _______________
7. What is your handicap? (Estimate and mark with an * if you are uncertain.) ________
8. When was the last time you played a full round of golf? _______________________
9. What was your score? ___________________________
10. What is the style (e.g., two ball, blade, belly) and brand of your putter? ___________

    ____
11. How long have you had this putter? ____
12. Do you have any previously diagnosed hearing problems? Y / N
    a. If yes, is your hearing corrected to normal with a hearing aid device? Y / N
13. What is your current level of fatigue? (1 = none at all, 5 = very tired)

    1 2 3 4 5
14. When did you eat last? ___________________________________
15. Are you currently taking any prescription medications? ________ If yes, please describe:

    ____

APPENDIX D

RANDOMLY GENERATED LIST FOR PUTTS

Randomly Generated List for Putts	Probe Position
1. 4	Catch
2. 3	3
3. 4	Catch
4. 1	1
5. 4	Catch
6. 1	1
7. 1	1
8. 2	2
9. 3	3
10. 3	3
11. 1	1
12. 3	3
13. 4	Catch
14. 3	3
15. 1	1
16. 4	Catch
17. 1	1
18. 2	2
19. 1	1
20. 4	Catch
21. 3	3
22. 3	3
23. 4	Catch
24. 2	2
25. 1	1
26. 3	3
27. 4	Catch
28. 2	2
29. 3	3
30. 1	1
31. 4	Catch

32. 2	2
33. 3	3
34. 4	Catch
35. 2	2
36. 4	Catch
37. 2	2
38. 4	Catch
39. 1	1
40. 4	Catch
41. 2	2
42. 2	2
43. 4	Catch
44. 1	1
45. 2	2
46. 2	2
47. 3	3
48. 4	Catch
49. 4	Catch
50. 2	2
51. 4	
52. 3	3
53. 1	1
54. 4	Catch

APPENDIX E

SCRIPT

Baseline Putting Trials:

"Today, you will be putting from two different distances on this platform. You will perform a series of putts from 6 feet, which is located at this black dot, and you will perform a series of putts from 12 feet, which is located at this black dot. I want you to perform your normal routine as if you were putting during a round of golf. Take your time and try to make them all. Do you have any questions before we begin?"

Baseline Reaction Time Trials:

"Now, I would like for you to take your normal putting stance and address the golf ball as if you were going to putt. Remain in this stance but do not actually putt. I am going to generate a series of tones from the speakers on this computer, and I would like for you to say the word 'ball' as quickly as you can in response to the tones. Do you have any questions before we begin?"

Dual-Task Trials:

"Now, you will be putting at the same time that you are responding to the tones from the computer. At various points during your putting stroke, you will hear a tone. I want you to continue putting while also responding by saying the word 'ball'. On some trials, you will not hear a tone. On these trials, simply continue putting as your normally would. On trials that feature a tone, respond as quickly as you can by saying 'ball'. Perform your normal routine, take your time, and try to make them all. Since you will be performing two tasks at once, I want you to focus on putting. Your primary objective is to make as many putts as possible. Do you have any questions before we begin?"