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Mental Representation Mediation in Expert Golf Putting

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FLORIDA STATE UNIVERSITY
COLLEGE OF ARTS AND SCIENCES

MENTAL REPRESENTATION MEDIATION IN EXPERT GOLF PUTTING

By
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Department of Psychology
in partial fulfillment of the
requirements for the degree of
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This dissertation is dedicated to Dr. K. Anders Ericsson, my mentor and friend, who was courageous enough to accept me as a student and stay with me through the ups and downs of the process. His encouragement and steadfastness in guiding my efforts were critical to the successful completion of this program.

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ABSTRACT

The current study is an initial investigation of expert performance theory in golf putting. According to Ericsson and colleagues (Ericsson & Smith, 1991; Ericsson, Krampe & Tesch-Römer, 1993), a performer's mental representations are the primary mediator of performance and the degree of refinement of those representations determine the level of performance in a domain. This study's purpose is to investigate golf putting performance in situations that require representational guidance to analyze, plan and execute putts in various putting situations. Using a screen to block visual access to the putting situation (occluded condition), this study examined expert and novice golfers in various putting situations to determine their ability to perform using only their mental representations to establish direction and distance when putting to targets of different lengths and over different terrain. Results showed that on a level putt from 23 feet, both experts and novices averaged within just over two feet laterally from the target (direction) and overall 3.5 to 5.5 feet from the target. This represents general competence in putting under occluded conditions, though none were trained in this condition. On substantially more difficult occluded putts, all golfers averaged within 10 feet of the target, on targets where they averaged more than 8 feet in the visible condition. Having acquired more refined representations, the experts, on the 23 foot occluded single target, were 35% more accurate than the less skilled golfers, and in the most complex putting situation (multi-breaking 28 foot putt), experts were 37% more accurate. These results support Ericsson and colleagues expert performance theories in mental representation mediation of performance and representational refinement mediation of levels of performance.

INTRODUCTION

The 2004 Masters golf tournament, one of the four major tournaments of the year, was coming to a close. Phil Mickelson, who had never won a major tournament, had come from behind and was even with Ernie Els at the top of the leaderboard going into the last hole. Els had finished and Mickelson had put his approach shot fifteen feet beyond the hole, leaving a tricky, downhill putt for a birdie and the win. He was in position to win his first major (and \$1 million). He watched as Chris DiMarco putted out and then proceeded to analyze his own putt, establish the line and, with seeming calm, roll the ball into the cup to win by one stroke. Under those conditions, most people, including many of the top tour players, would have missed. Mickelson, himself has missed many putts of that length and shorter. In truth, PGA Tour golfers have been shown to sink only 17.3% of 18-foot putts (Diaz, 1989). Yet many tournaments are won or tied on the last hole by sinking a pressure putt.

How do the truly world-class players manage to sink putts with a tournament victory on the line? The answer may be in expert performance theory and the acquisition of superior domain mental representations through deliberate practice. This study will attempt to provide insight into expert performance and how superior mental representations guide the truly great players.

In a groundbreaking study of musicians, Ericsson, Krampe & Tesch-Römer, (1993), posited that mental representations are the mediating mechanisms that govern performance. In addition, they found that performance improved as representations are refined in a monotonic relationship with the number of hours of lifetime deliberate practice (practice specifically designed to improve performance). Although Ericsson and colleagues expert performance theory has been examined by many other researchers, they have largely concentrated on the deliberate practice postulation and left the mediation of more refined mental representations as an *a priori* hypothesis (see Ericsson 2002 b; Ericsson, 1998; Ericsson & Lehmann, 1996 for summaries).

The purpose of this study is to investigate skill in golf putting, a common sport domain (estimated 27 million golfers in U. S.), in an attempt to identify the mediating

mechanisms that guide expert and world-class performance (PGA of America, retrieved October, 2007). In general, expert golfers use fewer putts per round than novices (DeGunther, 1996; PGA Tour Statistics, 1996). This study proposes to determine what cognitive mechanisms mediate this result.

It is hypothesized that some or all of the elicited mechanisms are also necessary for expert performance in many domains and will support the theories advanced by Ericsson and colleagues (Ericsson, 2002a; Ericsson et al., 1993; Ericsson & Smith, 1991). If so, mediating cognitive mechanisms found in golf putting can be useful in the future training and development not only of golfers, but also for performers in many other domains. The importance to future golfers can be vital to success, since more than half of the tournaments in 2004 were won by only one stroke, or a tie playoff, in four rounds of golf (usual par: 288 strokes) (PGA Tour Tournaments, 2004).

The approach to this study will be to establish basic putting skill by first determining participants' abilities to execute the putting task in a single target putting situation that requires minimal representational analysis of direction and distance. The tasks are performed on a regulation putting green insuring that the tasks are representative of normal golfing conditions. When that baseline is determined, individual differences can then be ascribed to cognitive processes based on mental representations. More difficult putting tasks will follow in order to extract the mental processes that expert and novice golfers employ in analyzing and planning the more complex putting situations. The resulting data from participants' putting performance and questionnaires will then be analyzed for evidence of performance mediators.

The introduction to the current study will first explain putting in the sport of golf and the necessary tasks that must be accomplished. Next, a methodology will be outlined for investigating the mediating mechanisms of expert performance in the domain. A brief discussion of skill acquisition and expertise will then follow. Lastly, a perspective on the role of mental representations in domain performance, and in golf putting specifically, will be advanced.

The introduction is followed by a review section of earlier work pertaining to the mediating effects of mental representations in several domains followed by a review of golf putting studies. An explanation of the current study and hypotheses follows. The

results and analyses of the measurements of each task are then presented followed by a discussion of the results in relation to mental representation mediation. Finally, a concluding summary of the results of the study will be presented, including follow-on investigations that may lead to further development of mediating mechanisms in golf putting.

The Putting Task

Early twentieth century golfing great, Walter Hagen, called putting the "game within a game" (Wiren, 1991). Putting appears to be a simple skill, but it is perhaps the most difficult aspect of the game of golf. In fact, one can explain the putting task to a three year old child in a sentence or two and the child will immediately produce an unsophisticated, but reasonable facsimile of a putting stroke. Contrast the child's performance with Phil Mickelson's performance that produced his winning putt at the Masters and it is quickly evident that the child has not developed Mickelson's representational or motor sense for putting. Yet Phil Mickelson's first attempt at a putt 30-some years ago was probably quite similar to the child's effort.

The putting domain constitutes three main factors: direction, distance and the putting stroke. A golfer determines direction by first "reading" the green. After being struck by the putter (stroke), a ball will roll according to many physical and environmental factors (Tipler & Mosca, 2003; Pelz, 2000). Putting experts generally analyze such factors as type of grass and length of cut, which affects green speed; direction the grass is growing, or grain; length of the putt; degree of slope of the terrain (left to right, up or down slope and proximity to the hole); dryness/wetness of the grass; impediments in the path and the speed and direction of the wind (DeGunther, 1996; Farnsworth, 1997; Pelz, 2000; Wiren, 1991; Woods, 2001). In addition, local conditions such as bodies of water (breaks toward the water) or nearby mountains (breaks away from high elevations) will affect the ball's direction (Pavin, 1996, DeGunther, 1996). Golfers may take some or all of these factors into account as they try to determine the point at which they will aim so that the ball will move to the hole as influenced by the factors operating on it (McCord, 1996; Wiren, 1991). Along with speed and direction, a golfer's mental representations of a putting situation are determined by his/her knowledge of these factors and their effects on a putt.

Distance. Distance control is provided by the length of the backswing, the putter speed as it contacts the ball and the acceleration through the ball after contact. This action imparts the energy required for the ball to roll toward the hole, and based on the green conditions will roll until gravity's pull and the friction of the ball on the green surface causes the ball to stop. If the ball rolls over the hole, and the speed is within the limits necessary for gravity to exert enough force to have it drop, the ball finishes in the bottom of the cup and the putt is made.

After hundreds of trials with his True Roller™, Dave Pelz (1989) determined that the optimum speed for a putt was that which would result in the ball finishing 17 inches beyond the hole if the hole was not there. This would give the ball the best chance of holding the line through the heavily trafficked area around the hole and still drop in the hole if the putt was on line.

Scientifically this is interesting, but developing the necessary ability, or touch, to consistently stroke a ball from different distances to finish exactly 17 inches past a given point is a complex cognitive/motor learning task. Golf books advocate many drills and techniques for speed control, but in essence it all comes down to developing consistency through practice. Many top golf instructors (e.g. Pelz, 2000; Wiren, 1991) conclude that more learning will occur with more practice trials supporting the monotonic relationship between skill level and deliberate practice (Ericsson, et al. 1993). With deliberate practice in putting for distance control, mental representations will develop that will allow the golfer to analyze the putting situation and estimate the force needed for the putting stroke (Ericsson, 2001a). Supporting the deliberate practice theory, Schmidt and Lee (1998) call practice the most important variable in motor learning. The ability to consistently stroke the ball to a predetermined distance is generally referred to in the golfing community as "touch or feel."

Direction. Reading the green is the process by which a golfer determines the direction in which the ball must be stroked with the necessary force to cause the ball to travel over the green's topography and reach the target hole. The path may be anywhere from an inch or two to sixty feet or more in length. Professional golfers strive for consistently high putting performance, since every putt missed can cost them thousands, even hundreds of thousands, of dollars in a tournament. Over many years of deliberate

practice and reading greens in high pressure situations, world class golfers develop extensive knowledge of the unique properties of thousands of greens and refine their mental representations of the ball's motion on these greens. Their knowledge of the effects of the green topography allows them to visualize a ball path that will account for the green's effects on the rolling ball and end up in the target hole. The golfer's task is to stroke the ball so that it follows that path to the hole (Pelz, 2000; DeGunther, 1996).

Stroke control. Since every putt is stroked as a “straight putt” directed at an aim point, offset to allow for the topographic and environmental conditions, it is most advantageous to perfect a stroke that will *consistently* roll the ball directly to an aim point. Going off line as much as one degree can cause a missed putt from just six feet or more. Developing a consistent putting stroke requires many hours of deliberate practice in addition to distance and direction knowledge. Without it, a golfer will not be able to putt well since he/she won't know precisely where the ball is going to roll.

In determining the effect of mental representations in golf putting it will be necessary to understand the ability of the participant to consistently stroke the ball toward a designated target. If a golfer cannot count on consistently stroking the ball in the same manner (e.g. push the ball some of the time and pull it at other times), he/she will be unable to line up properly for a given putting situation. If that's the case, reasoning and planning a putt is a futile exercise.

In the current study, stroke consistency will be tested with tasks requiring minimum reasoning and analysis, thus focusing on the stroke execution. Once it is ascertained that participants can consistently approximate the same stroke, it can be eliminated as a variable of interest. Then more complex putting situations requiring reasoning and planning can be set up to evaluate individual differences in mental representations used to analyze each putt. These will be defined in the Current Study section.

Expertise Approach

In order to extract the guiding mechanisms from expert performance in a domain, a method for inferring the performer's non-observed cognitive processes as well as observed behavior is necessary. In 1991, Ericsson and Smith proposed an empirical approach to the study of expert performance. Using this methodology, mediating

mechanisms are elicited through detailed analysis of observed behavior and verbal protocols in representative tasks, and a subsequent determination of how the mechanisms are acquired. This method initially requires the identification of representative domain task(s) that can be run and reproduced under laboratory or controlled conditions and that capture the superior performance of experts. The next step is to analyze the cognitive processes that are the essence of the superior performance. Once the mediating cognitive processes are isolated, experimental tasks can be designed that isolate the critical aspects of the performance. Finally, and most useful, determining how the identified mechanisms can be acquired through training and practice (Ericsson & Smith, 1991). The domain of golf putting provides an excellent format for the study of expert performance since the representative tasks can be performed in its natural environment under ecologically valid conditions. The Current Study and Method sections will detail this study in relation to the expertise approach.

Constructs of Skill Acquisition and Expertise

Skill acquisition theory posits learning in three progressive stages: 1) the cognitive stage, 2) the associative stage, and 3) the autonomous stage (Anderson, 1982; Fitts & Posner, 1967). In the cognitive stage, subjects commit to memory a set of “facts” regarding the task(s) to be learned or an encoding in declarative memory. At this point, performance is highly irregular as no defined procedure was yet available in memory. In the associative stage, errors are gradually eliminated and connections between the required skill elements are strengthened. From this, a procedure is developed that will result in successful performance of the task(s). Lastly, in the autonomous stage the procedures become more automated requiring decreasing conscious attention. Only when something unusual occurs in the performance of the task does the subject become aware of the situation and take action based on conscious reasoning. For instance when driving home from work or school, the driver may be talking to a passenger and be unable to recall any of the traffic conditions upon reaching home. However, if a car in front goes out of control and evasive action must be taken to avoid an accident, the subject will quickly become consciously aware, analyze the situation and take evasive action to attempt to avoid a collision.

Developing a skill to the level of automatic performance may explain performance in many daily activities, such as driving, but it doesn't allow for expert performance, since the highest levels of performance in a domain require continued improvement beyond automaticity. If behavior is automatic, one cannot consciously operate on it to upgrade the level of performance. For instance, if most experienced drivers were to operate their automobile at the Daytona 500, they would most likely put themselves in great danger. Only by superceding their automatic learning might they develop the necessary skill to operate a racecar in racing conditions. It would be the same in putting a golf ball. One can easily develop a golf stroke to the level of automaticity, but to attain expert performance levels one must have conscious awareness of the critical aspects that are necessary to discern an accurate ball path, to stroke the ball along that path at the correct speed and to perform at a higher level and to evaluate one's current performance in relation to higher performance goals.

As noted earlier, the overall theory of expertise is based on the concept of deliberate practice and the subsequent development of domain specific cognitive skills that mediate expert performance (Ericsson, 2006; Ericsson et al., 1993). This theory argues that there is a monotonic relationship between skill level and the total amount of deliberate practice in the domain. The results of deliberate practice are more refined mental representations of, and physical adaptations to, the task requirements and constraints of the domain. Further, cumulative deliberate practice and resulting feedback develops increasing levels of domain knowledge and more refined mental representations. A performer's mental representations of the current situation are the basis for planning, reasoning, anticipating and controlling motor production to best reach the desired goal (Ericsson, 1998; Ericsson & Lehmann, 1996). Thus, more refined (complete) mental representations provide the basis for more accurate reasoning and planning in task execution.

Mental Representations

Highly skilled performers in many domains have acquired complex mental representations that give them greater accuracy, more control and flexibility when performing (Lehmann & Ericsson, 1997). The process generated by deliberate practice, feedback and analysis are encoded and stored in the performer's developing retrieval

structure in LTM (Ericsson & Kintsch, 1995). This process increases domain specific knowledge and creates and refines one's mental representations of desired goals and the current situation with respect to the goals. Through analysis based on a performer's mental representations of current situations and goals, he/she can reason and develop plans for strengthening areas of weakness and setting higher performance goals that will take him/her to the next skill level.

In many domains, skilled performers must monitor their current situation in order to be able to plan, reason, anticipate and control motor functions prior to and while performing the requisite task (Ericsson & Lehmann, 1996). Refined internal representations allow for accurate evaluation of the current situation against the performance goal and let the skilled performer effectively assess alternative actions to attain the goal (Ericsson, 2004, 2003, 1998). Performance feedback also interacts with one's domain knowledge and mental representations. This allows the performer to further analyze and plan his/her ongoing performance and reaction to changing conditions.

As noted earlier, the level of performance in a domain is monotonically related to the accumulated amount of deliberate practice Ericsson, et al. (1993). Part of the reason for this effect is the accumulation of domain specific knowledge and the refinement of task specific mental representations. At least three types of mental representations mediate skilled performance: a representation of the performance goal, a representation of the current performance state and a representation of procedural requirements to meet performance goal (Lehmann, 1997). These representations, developed and enhanced through coaching instruction, self-monitoring, feedback and increasing level of performance attainment, are fluid and are continuously refined during practice and performance.

Behavior Mediated by Mental Representations

The concept of mental representations has led to considerable theoretical discussion regarding their existence, their function in behavior, and their acquisition and structure. For example, behaviorism disregards mental processes, though it may allude to thinking under the guise of implicit language activity and any other gestures and movements intended to communicate meaning (Watson, 1913, 1920; Skinner, 1953).

Other investigators modeled cognitive functional processes such as thinking, analyzing, planning , problem solving, decision making and intention (Paivio, 1971).

Empirical evidence of mentally representing information has been elicited as early as the late 1800's with the study of what has been referred to as "nonsense syllables" (Ebbinghaus, 1913). Ebbinghaus was attempting to investigate "pure" memory capacity by using lists of meaningless syllables as stimuli to insure new learning (encoding). Interestingly, it was found that subjects still attempt to apply meaning to the stimulus in some way within their sphere of knowledge and association (Ashcraft, 1994). By applying meaning to the "nonsense" syllables, subjects thus indicate that they have a mentally represented word or object with which to associate the new stimulus. Even the behaviorists would, at times, depict mental processing in a behavioral context. For instance, C. L. Hull's concept of the pure stimulus act whose function is to generate self-stimulation that, in turn, can mediate further responses (from Paivio, 1971, p. 43). Thus the stimulus is internalized and used later to mediate further behavior. In 1948, E. C. Tolman advanced the concept of cognitive maps, a form of mental representation, in describing the activities of rats in a maze. According to Tolman, "...it is this tentative map, indicating routes and paths and environmental relationships, which finally determines what responses, if any, the animal will finally release" (Tolman, 1948, p.192).

Another early study elicited a concept of mental schemata that suggested that memories are constructed by combining some parts of the original information with existing knowledge (Bartlett, 1932). In an experiment involving the reading of a story, recalling it 15 minutes later and then again after 4 months, Bartlett found that there were significant omissions in recall and that story gaps were then filled in with the subject's own knowledge, which had the effect of "normalizing" the story. The subjects' had apparently created a schema, or type of mental representation, of the story and simply recalled from this representation their encoded version of it.

Early cognitive investigators included George Miller, who advanced a theory of limited short-term memory (STM) and the concept of "chunking," based on digit span experiments, and the inability of the average person to recall more than "seven plus or minus two" digits when presented at one digit per second (Miller, 1956). Chunking was

conceived as accumulated items of related information that would be stored and recalled as a unit. Thus a “chunk” is a basic mental representation of learned information.

Concurrent and subsequent to Miller’s seminal revelation, evidence of mentally represented information has produced a huge body of research into the encoding, storage and retrieval of information and the processes by which humans utilize the information to produce behavior (e.g. Schneider & Shiffrin, 1977; Baddeley and Hitch, 1974; Chase & Simon, 1973; Chase & Ericsson, 1982).

Nonverbal or image representations are relevant to the normal process of golf putting. Other than the early representational evidence above (Bartlett, 1932), it has been shown that humans can produce internal representations of objects and events and manipulate them as desired. Perhaps the most impressive examples of mentally representing nonverbal information come from demonstrations of mental rotation (Shepard & Metzler, 1971; Cooper and Shepard, 1973). In Shepard and Metzler (1971) subjects were shown a complex drawing of three-dimensional objects from two different angles and they were to determine if the two were the identical shape. In order to make a correct determination, the subjects mentally rotated the first drawing to the position of the second drawing and compared them.

In Cooper and Shepard (1973), subjects were visually presented with either a letter or digit randomly rotated in 20-degree increments in either a normal or mirror image position. The results supported the concept that during preparation of a tilted stimulus, the subject carries out a mental rotation of an internal (mental) image of the anticipated stimulus (test letter/digit). A second experiment involving auditory pre-test presentation, auditory movement instructions and test stimuli in the expected or non-expected position produced the expected linear results based on rotational distance from the expected position.

Based on these experiments, it can be projected that humans develop mental images/representations of objects and events and can mentally manipulate them at will. In fact, Cooper & Shepard (1973) suggested that the ability to mentally maneuver mental representations would be useful in areas from rearranging furniture, to geometry problem solving to theoretical physics to gymnastics to solving topographic problems (an ability required for reading a golf green). This provides support for the thesis that mental

representations can be used as the basis for goal setting, anticipation, analysis, problem solving, and planning in many different problem situations (Ericsson, 2002b, 1998; Bédard & Chi, 1992; Paivio, 1986).

The continuous comparison of one's current performance state and preferred result allows the performer to analyze, reason and plan for subsequent control of actions that can produce progressively better results.

Novice and expert performers differ in the completeness and organization of their mental representations. McPherson (1993b) reviewed three empirical studies using verbal protocols showing that more highly skilled participants have more complex and sophisticated mental representations while novices had more general approaches to situations indicating a less developed internal representational base. From this it appears that less skilled performers are not able to account for all *relevant* constraints, and/or ignore non-relevant information, that the expert uses as a basis of strategy development and performance methodology and will thus not account for all factors that mediate superior performance. Enhanced mental representations allow one to exert greater control over relevant aspects of performance, to understand both familiar and new situations and to plan and reason about alternative actions (Ericsson, 1998).

Feedback. Feedback is a critical element in the refinement of mental representations. Teachers/coaches provide performance feedback to a student and help to put it in perspective within the context of the task. In turn, the students must learn to interpret feedback for themselves so they can continue to learn and develop strategies for improvement when their teachers are not available or when they've learned all that they can from their teachers. This requires sophisticated mental representations of the desired performance and a conscious sensitivity to their concurrent performance (Ericsson, 1998). They will then be able to reason and plan their own strategies for enhancing their performance to more closely approximate the desired performance.

The concept of mental representation mediation of performance can provide a working explanation of golf putting. First, it establishes a basis for goal direction and a mechanism for enlisting pertinent domain knowledge of environmental effects on rolling golf balls. Second, this approach provides the basis for reasoning about the situation and planning of the action required prior to execution. Finally, a representational explanation

accounts for analysis of results, evaluation of performance errors, assimilation of these new results in the task representation and planning for future situational analyses.

Mental Representations in Golf Putting

In order to investigate the necessity of positing mental representations in golf putting performance, it is necessary to pursue the cognitively based explanation that we use mental representations as a means of planning and controlling our actions (Ericsson & Lehmann, 1996). World class performers in many domains from mental calculation, to chess, to sports, have achieved performance levels far beyond what would appear to be skills that have been trained to an automatic level (Ericsson, 1996; Anderson, 2000). In order to explain expert performance, we must look beyond automatic, condition-response mechanisms.

The ability to set goals, analyze and reason, solve problems, make effective decisions, plan actions and control and direct motor functions is integral to effective domain performance (Ericsson & Lehmann, 1996; Ericsson, 1998). The more efficiently and accurately that these functions are executed can lead to higher performance on domain tasks (Ericsson, et al., 1993; Ericsson, 2001b). The informational foundation of these cognitive processes is one's internal representations of the domain and the domain tasks.

According to the Dictionary of Psychology (Reber & Reber, 2001) a representation is "A thing that stands for, takes the place of, symbolizes, or represents another thing." In psychology, a mental representation is a direct mapping, an elaboration, a mental code or an abstract characterization of a stimulus event (Reber & Reber, 2001). Cognitive structures have been described as "a nonspecific but organized representation of prior experience" (Neisser, 1967, p287). To simplify the concept, this study will view a mental representation as *all of a performer's acquired domain information categorized and procedurally organized according to his/her basic understanding of the domain and/or domain tasks*. Thus, a golfer's mental representation of golf putting will include all semantic and procedural knowledge regarding the putting tasks and the episodic information gained from practice and experiential feedback (Tulving, 1972; Anderson, 1982).

Task structures, rules and goals, along with the procedures to attain those goals, are posited to be internally or mentally represented (Paivio, 1971; Neisser, 1967). The representation(s) in turn act as one's base reference for task accomplishment. From his/her representation, a golfer can "overlay" the current putting situation, establish the goal, reason through the constraints in rolling the ball to the target and select the expected ball path, estimate the aim point required for the ball to follow the ground contours to the target, heuristically understand the distance requirement and the force required on the ball, go through the physical procedure embodied in his/her representation and finally strike the ball toward the hole. With no internal representation of the domain, it would not be possible to effectively perform the task without some exogenous control mechanism.

Spatially oriented representations as one would require for golf, are often equated with mental images. In his dual coding theory, Paivio (1971) labels his nonverbal representational subsystem as the imagery system. He further defines mental images as conscious representations of our knowledge of the world (Paivio, 1980). Within his theoretical concept, mental representations can be used as the information base for cognitive operations and can aid in new learning. Mental representations are thus posited to be the bases for judgments, computations and inferences that depend on one's represented knowledge (Ericsson, 2006; Ericsson & Lehmann, 1996). In addition, they can be consciously manipulated for problem solving and creative purposes (Baars, 1986; Shepard & Metzler, 1971; Paivio, 1980, 1986). This is in concert with the Ericsson (2002a, 1998) expert performance thesis that increasingly refined mental representations allow the performer to gain more control of relevant aspects of performance requirements and allow them to analyze, reason and plan courses of action that will allow them to attain higher levels of performance and to continue to learn and maintain current performance levels. In addition, the more complete and refined the representation, the more performers can project the desired performance accurately and to monitor and critique their current performance (Ericsson, 2001b).

When reading a putt, golfers will most often position themselves behind the ball and look toward the hole to get an idea of how their ball will roll. In general, this is the only perspective from which a novice golfer will develop a representation of the putt. If

one watches professionals at a tournament, it may be noted that they will often also look at the putt from the side, to see the degree of the upward or downward slope from the ball to the hole. Then they will observe from the hole to the ball from which they can judge the side-to-side slope from a different perspective. The professional thus fine-tunes his read and represents the projected putt for both direction and distance. Novice putters on the other hand are more likely to read the putt from behind the ball only, perceive a general idea of the slope of the green and distance to the target and then set up to putt (Hill, 1999).

Based on one or more factors as the golfer sees them, he/she will make a determination of the "break" the ball take when rolling to the hole. Keeping this mental representation in mind the golfer will address the ball and stroke the putt, aiming to the left or right of the hole based on how much break was calculated. All putts should be treated as straight. The difference is the aiming point the golfer selects and the correct position of the face of the putter. Then the ball is stroked toward the aim point and gravity will determine the path to the cup (Wiren, 1991). In order to predict how gravity and topographical conditions will guide the ball to the hole, however, one must establish a mental representation of the predicted path through reasoning and planning based on their previously acquired representations and the current perceived situation.

Mental imaging of a putt's desired path may be thought to be an extension of one's mental representation of the putt. Several studies have shown that positively imaging a putt and its successful result prior to the actual stroke results in greater putting accuracy (Woolfolk, Parish & Murphy, 1985; Meacci & Pastore, 1995).

Unique to golf is the change in perceptual perspective between the position of the initial read of the green and the position from which the golfer must make the putt. The visualization of the putt must be translated from the perspective taken from behind the ball to the perspective from the address position at the side of the ball (Farnsworth, 1997). It is not clear how this change in perspective influences the golfer's stroke. There is a possibility that this could affect the golfer's eventual aim point and influence the accuracy of the putt. However, according to the ecological cognitive perspective, all significant points of orientation are static regardless of one's observing angle (Gibson, 1979).

Review of Past Findings in Expert Performance

Evidence of Mental Representation Mediation in Expert Performance

The level of domain knowledge is thought to be a prime indicator of performance level. According to Ericsson & Charness (1994), to consistently perform at the highest level, one must have mastered all the available domain knowledge. Thus the expert performer understands what information is relevant to the successful performance of the specific task and ignores information that is not. Novices on the other hand tend to evaluate non-relevant information leading to possible false or less effective conclusions that are derived more slowly than experts (Glaser & Chi, 1988)

The use of mental representations in the mediation of resulting behaviors has been suggested by studies in many domains: in blindfold chess (Saarilouma, 1991; Holding, 1985) and in chess (Saarilouma & Kalakoski, 1997; Gobet & Simon, 1996; Chase & Simon, 1973; Charness, 1976; deGroot, 1946/1978), in music (Lehmann & Ericsson, 1997b; Ericsson et al., 1993; Halpern & Bower, 1982), in medicine (Patel & Groen, 1986), in physics (Chi, Feltovich & Glaser, 1981; Larkin, McDermott, Simon & Simon, 1980), in mental calculation (Staszewski, 1988) and in sport (McPherson, 1993a; Allard, 1993; Abernethy, 1991). To examine the proposition that mental representations are major mediating mechanisms that underlie skilled performance, it is necessary to reject the hypothesis that such behavior can occur without them. In mostly mental domains such as mental calculating and blindfold chess, analysis and problem solving are integral and representations of intermediate steps and board positions are critical. Motor domains such as ballet and various sports not only require representation based analysis and problem solving, but also anticipation, physical behavior and timing. This section will explore the evidence of representational mediation from highly mentally oriented domains such as chess, through music, ballet and conclude with sport activities.

Chess. Chess is played on an 8x8 matrix of 64 squares with chess situations described with row numbers and column letters (i.e. *a1* through *h8*).

Expert players can play multiple games blindfolded using this representation scheme to understand moves being made and to keep all games mentally in process simultaneously (Holding, 1985). In this way, they represent and retrieve each board in play and thus maintain current play situations. As play continues, the expert player can

utilize his/her board representation to analyze each current situation and determine high quality moves for each board in turn (de Groot, 1946/1978, Chase & Simon, 1973)..

In sum, initially a chess master retrieves potential moves based on their representation of the situation, where superior representations result in better moves in line with strategic goals. If time permits, a more detailed search allows for evaluation of alternative moves and reduced oversight of better moves, producing superior performance even among experts (Ericsson and Lehmann, 1996).

Music. In the musical domain, solo performers often produce technically error free renditions of musical scores that they have memorized. However, knowledgeable music critics will note many differences in the quality of performance based on concepts beyond technical perfection. Performances differing in tempo, emphasis, amplitude, tone, etc. can distinguish the world-class performer from the strict constructionist.

Lehmann & Ericsson (1997a) illustrated the use of mental representations in musical presentation when they asked skilled pianists to memorize two 8-measure segments from Franz Schubert's sonata for violin and piano (op. 137, D384). Each subject then practiced one of the two pieces until they could reproduce the score from memory two times without error. They were then asked to: 1) play the memorized piece at faster and slower tempos; 2) to reproduce the right hand only, then the left hand only; 3) to reproduce only the odd numbered measures and then the even numbered measures; and finally, 4) transpose the musical segment from its original key of F to F#.

In all cases, the musicians were highly accurate in their reproductions. Since they were performing from memory, it provides support for the proposition that they were using their mental representations as a basis for initially duplicating the score as written and then for changing tempos, alternating the even and odd measures, separating the right and left hand parts and finally transposing the key from F to F#.

Ballet. In ballet, Smyth & Pendelton (1994) tested professional ballet dancers and non-dance trained novices (undergraduate students) in memory for meaningful ballet movements and non-meaningful random movements. Memory spans were greater for experts in both ballet and random movement conditions and experts took only about half the number of trials to reach criteria for task participation, as did the novices.

Interestingly, both experts and novices recalled somewhat more "nonsense" movements

than ballet movements, perhaps because of their novelty. Smyth & Pendelton (1994) noted that expert dancers are better at linking movements stored in long term memory than are novices, even when those movements are not from the dance repertoire.

The fact that experts' memory spans were more extensive and that they were able to link movement sequences together suggests that they have memory cues to movement representations in long term memory and are able to find familiar patterns in which to compare and link new dance movement information. It is reasonable to conclude that dancers link the movements in order and create a mental representation (or cognitive map) based on other familiar sequences.

Sport. In sport the use of information constructs, from domain knowledge to reasoning and analysis has been documented in sport literature: in tennis (McPherson & Thomas, 1989; Goulet, Bard & Fleury, 1989), in field hockey (Starkes, 1987), in badminton (Abernethy & Russell, 1987; Abernethy, 1989), in soccer (Williams & Davids, 1995, 1998; Helson & Pauwel, 1993), in figure skating (Deakin & Allard, 1991), in table tennis (Ripoll, 1991), in marathon running (Laasch, 1995), and in orienteering (Eccles et al. 2002). In addition, measurement and comparison of expert and skilled players' domain knowledge bases is shown to be consistently greater for the higher skilled performers (Allard & Starkes, 1991; Starkes, 1987; Nevett & French, 1997). This evidence supports the accepted proposition that performance in sport relies on a player's ability to evaluate the task situation, solve problems presented by the task situation, make timely decisions and produce accurate and effective action responses (McPherson, 1993b).

Findings show that highly skilled sport performers have access to different problem representations and knowledge bases during performance than do novices and beginners (French, Nevett, Spurgeon, Graham, Rink & McPherson, 1996; Paull & Glencross, 1997; McPherson, 1993b; French & Thomas, 1987). Knowledge bases for sport are considered to include sport specific concepts plus procedures for response selection and execution. These sport specific structures are in retrievable memory and are posited to include representational constructs such as action plan profiles, current event profiles, game situation prototypes, scripts for competition and sport specific strategies (French & McPherson, 1999). In each of the studies, subjects were confronted with

problem situations either in actual play (McPherson & Thomas, 1989; French, Werner, Rink & Taylor, 1996) or presented audio/visually (French & Nevett, 1993; McPherson, 1993b). Participants were thus required to represent and verbalize the task specific problem situation.

In another study, McPherson & Thomas (1989) investigated young tennis players using two age group conditions and two skill level conditions. Analyses of the verbal protocols revealed that experienced children, regardless of age, exhibited more sophisticated knowledge representations. Their task representations were more complex conceptually with more refined physical or abstract tactical features. Experts reported associated concepts that reflected linked relationships between the concepts. Novices on the other hand, were more general in their problem solving approaches. Both skill levels had similar goal objectives, however novices responded with vague or no associations between concepts and less detailed action concepts.

The results support the expert performance hypothesis that higher level performers have developed more refined mental representations of domain tasks and that these representations mediate the players' actions during performance (Ericsson, 1998, 2001a; Ericsson & Lehmann, 1996).

In summary, cognitive mediation of expertise, may be considered as the acquisition of the available domain-specific knowledge through a minimum of approximately ten years of deliberate practice and feedback from teacher directed tasks (Chase & Simon, 1973; Ericsson et al., 1993; Ericsson & Charness, 1994). This continuous long-term effort produces the ability to use one's long term memory as working memory (long-term working memory) in the domain and to develop highly refined mental representations of the desired performance and the current state of performance (Ericsson & Delaney, 1998; Ericsson & Kintsch, 1995). With these acquired mechanisms, the skilled performer can plan, reason and anticipate what are the best possible actions to meet performance goals and direct the necessary motor movements (Ericsson & Lehmann, 1996; Ericsson, 1998, 2001a). Since novices have not acquired highly refined mental representations of the domain, their reasoning and analyses cannot support expert level performance.

Expert golfers would thus be expected to have acquired these same domain-specific cognitive mechanisms while less skilled golfers would be limited in these same abilities. Next we will evaluate expertise in the precise skill of putting in golf, and report on the current study that examines these mechanisms in expert and novice golfers.

Evidence of Mental Representations in Golf Putting

As evidenced in the literature above, many domains reveal the probability of internally stored representations of task parameters as necessary for total task performance. In order to answer the basic question, it is now necessary to ascertain if the evidence reported in golf putting exhibits the same requirement for representational mediation in task performance.

Research into the domain of golf putting is relatively limited and is largely divided into four main categories: 1) The mechanics or physics of putting including the effects of the topography on the rolling ball (DeGunther, 1996; Mahoney, 1982; Jorgenson, 1999; Pelz, 2000); 2) Equipment effects of different putting clubs on putting performance (Gwyn, Ormond & Patch, 1996); and 3) The physical performance of setting up and stroking the ball (Wiren, 1991; Gott & McGown, 1988). This “how to” body of literature is helpful for beginning golfers and for experienced players who may need to re-experience the basics. However, the information only provides putting set up and execution knowledge which is assimilated and can become the base knowledge for the mental representations of physical putting actions.

For the purposes of this study, however, the most meaningful research on golf putting performance relates to the effects of cognitive and motor functions on the putting task. The mind/body/instrument synergy required to perform the putting task incorporates problem solving, procedural knowledge and physical execution of the putting stroke. If a golfer is able to accurately predict the ball path, he/she has a refined mental representation of the rolling action of the ball in this situation. If he or she can consistently stroke the ball from 20 feet so that it rolls within a makeable distance for the next putt, he/she has a refined heuristic representation of force control.

Some areas of investigation, including pre-shot routines, imagery/visualization, occluded vision and putting consistency, with direct implications for mental representation mediation, are discussed below.

Pre-shot routines. The pre-shot routine is one golf putting function that provides some evidence of mental representations in golf putting. According to one PGA Tour professional, “every good golfer follows a certain routine on every shot, and this routine is especially important in putting” (Floyd [with Dennis], 1989, p. 59). Pre-shot routines are set behaviors and thought patterns that golfers use prior to actual stroke execution to enhance performance (Crews & Boutcher, 1986; Wiren & Coop, 1978). According to Tiger Woods, golf’s number one player and winner of eight professional Major Championships, sticking to a good pre-shot routine, allows him to analyze the key elements of a shot and stay in rhythm (Woods, 2001). During the set routine, a golfer will have assayed the green’s topography, the environmental conditions prevailing at the time, observed the ball-target distance and estimated the force of stroke necessary and established an aim point toward which to stroke the ball. Many professional golfers state that they visualize the putt rolling along the expected path to the hole (Nicklaus, w/Bowden, 1974; Floyd, w/Dennis, 1989). Positive visualizing, or imaging, the ball’s expected path as part of a pre-shot routine has been shown to have a positive effect on learning and performance (Woolfolk, Parrish & Murphy, 1985; Beauchamp, 1999).

In summary, pre-shot routine evidence provides some, but inconclusive, support for the theory that mental representations mediate putting performance and provide the motor system with the goal direction and “feel” for the stroke execution.

Imagery and visualization. According to Paivio’s (1986) dual code theory of mental representation, there are two ways of mentally representing information: a verbal form and a spatial form. Imaging a golf putting situation would utilize the spatial representational capability while instructions and self-talk pertaining to the situation would be verbally represented and perhaps be more applicable to the procedural aspects of the putting task. If imaging is, in fact, a form of mental representation and there is a difference in expert and novice golfers in the use or non-use of imaging, it would provide some evidence that mental representations contribute to the differences (Paivio, 1971).

Surveys of Olympic athletes and coaches report that mental practice and imaging has become a standard training tool (Suinn, 1997, Ungerleider and Golding, 1991). In 1984, sport psychologists assigned to U. S. Olympic teams ranked imagery training as one of their top training techniques (Suinn, 1985). Unfortunately none of these surveys

reported any significant positive effects of the imagery/mental practice on the Olympians' performance.

Positive effects of imagery have been found in several sport domains, however, many of the studies are only effective in certain situations or for certain participant cohorts. Wichman & Lizotte (1983) showed a significant improvement in dart throwing performance (18 throws before and after imagery intervention) in the mental practice group, but no (or negative) improvement in the control group. The gains were stronger for the internal locus of control group than for the external group. A tennis study (Noel, 1980) showed imagery practice resulted in an improvement from pre-tournament to tournament serving (% of first serves in) for high ability tennis players (A & B level), but a performance decline for low ability players (C & D level). The study of imagery use by figure skaters (Rodgers, Hall & Buckolz, 1991) showed an improvement by both verbal and imagery trained skaters in completion of their program elements and their performance scores, as rated by an independent figure skating coach.

Mental imagery and practice are necessarily based on mental representations of domain tasks to be performed. The dart throwing study found superior results for those with an internal locus of control reflecting the use of their representations as they normally would to mediate their performance. External control representations may be more effective for observers (e.g. judges). High ability players as in the tennis study are theorized to have more refined mental representations, thus they would be able to image the service task more realistically than one with less refined representations. In the figure skating study, both experimental groups were using techniques that are intended to actively stimulate their mental representations and thus focus on the representations of the desired goal.

All studies may be indicative of a sharpening of their representational focus on their immediate performance and goal attainment. It does not, however, verify mediation of performance, but rather provides focus on the derived ball path. The actual domain mental representation is the basis for both mediation and imagery or mental practice.

Golf is a domain that lends itself to imaging shots prior to execution. As with other sports, many professional golfers use visualization or imaging of the expected path

of the ball and eventual drop in the cup as part of their green reading and pre-shot routines. Jack Nicklaus, the most dominant player of his time, has stated that he “never hit a shot, not even in practice, without having a very sharp, in-focus picture of it in my head...like a color movie” (Nicklaus, 1974, p. 79). Several studies have investigated the use of imagery, visualization and mental practice in the domain of golf putting with mixed results (Woolfolk, Parrish et al. 1985; Woolfolk, Murphy et al., 1985; Beauchamp, 1999; Thomas & Fogarty, 1997). However, studies of expert or highly skilled golfers indicate that imagery/visualization is a key part of their preparation for each shot. When five professional golfers (28 total wins on the PGA Tour) were asked to describe their all time best putting performances in detail, an unusually clear mental image of the putting situation was a notable part of each description (Beauchamp, 1999). In another study, thirty skilled golfers (USGA handicap of 10 or less) played a nine hole putting course twice. The first nine were played without intervention to establish a baseline performance level. Prior to playing the nine holes a second time, fifteen of the golfers listened to a 5 minute imagery audio tape while the other fifteen completed a survey. Results showed that the intervention group improved significantly in the second nine holes over their first nine holes, while the control group improvement was small and not significant. Since there were no significant improvements in the control group results, practice effects, if any, are considered minimal (Cook, Horvath & Connelly, 1989).

The reports of the use of positively imaged mental representations by expert golfers do indicate a contribution to their performance and a refined mental representation of a successful task performance (Cook et al., 1989). This would be consistent with the weaker results achieved by beginners, since a weakly defined or incorrect “map” would not be sufficient to direct the proper set up and execution of the task.

The literature on the use of imagery in golf putting provides some indication of possible mediation of mental representations in the putting task. Of course, some of the differences observed in beginners and novices may be attributable to the lack of consistency in their putting stroke and their ability to hit the ball on the selected line. These results appear to be consistent with the expert performance theory that posits that mental representations (image bases) are more highly refined in experts and skilled

performers based on higher levels of knowledge and pursuit of improved performance or deliberate practice (Ericsson, 2001b; Ericsson, 2001a).

Occluded-vision investigations. In the search for evidence that mental representations mediate skilled performance and are a significant factor in individual differences in performance, depriving the performer of visual input from the current situation as they perform the task might be the most compelling. The previously noted, studies involving blindfold chess and tempo changes in piano performance of memorized music are strong indicators of mental representational mediation in goal oriented behavior. Without visual input or stimulation, the subject must rely on mental and kinesthetic processes to provide the situational awareness necessary for performance. In addition, superior performance under occluded conditions may indicate more complete and useful mental representations for mediating action, even in conditions with available visual perception.

In an earlier study, golfers were taught to drive the golf ball with and without visual access to the ball. The blindfold group made nearly the same progress as the visual group. Surprisingly, at the end of the training, the blindfold group quickly surpassed the group that had learned visually (Griffith, 1928). This gives support to the need for forming strong mental representations during training.

Several studies involving occluded vision in the golf putting task have produced significant evidence that those who mentally represent (and/or image) putting situations without visual contact can perform as well as those with direct visual contact (Meacci & Pastore, 1995; Aksamit & Husak, 1983; Anderson & Mayo, 1999). In contrast, another study found that participants using relevant visual cues performed better than those without visual cues (Wannebo & Reeve, 1984). Unfortunately, these studies have used beginning and novice players leaving expert performance under occluded conditions for future evaluation.

Other relevant studies. Other relevant lines of investigation are visual characteristics of expert putting performers (Naito, Kato & Fukuda, 2004; Vickers, 1992) and cognitive interference in pressure situations (Beilock & Carr, 2001). In an interesting putting study, Vickers, 1992 compared experts and novices visual routines and found that

just prior to stroking the ball, experts held their gaze longer on their point of focus than novices did. This “quiet eye” technique may be the expert golfer’s way of maintaining a consistent inner stabilization just prior to beginning their motor function. In another study, Naito et al., 2004 measured the eye movements of expert, intermediate and beginning golfers. Their results showed that intermediate and beginning golfers had longer fixations on the ball which did not move until the ball had been struck. Experts on the other hand, did not fixate on the ball, but rather behind the ball until just before they made contact with the ball, at which time they rotated to a point just in front of the ball. The authors suggested that the experts might have been relying on their mental representation of the ball, while the other golfers relied on direct visual access.

In a recent study of “choking” in pressure situations, two theories of performance under pressure were examined (Beilock & Carr, 2001). Distraction theory posits that pressure serves to create a dual-task environment, where those not trained in dual-task performance would be adversely affected by the secondary “task” intrusion, whereas those trained in dual-task performance would not be affected. Explicit monitoring theory suggests that practice results in integrated task procedures allowing for less conscious involvement in the performance. As such, pressure prompts individuals to attend to the skill execution processes, interrupting the smooth effectuation of the task. Results support the explicit monitoring theory indicating that focusing on the individual execution processes as one would do while learning precipitates disintegrated execution and thus poorer performance.

Putting consistency. An unpublished study relating to mental representations in golf putting shows that although experts actually putted more accurately than novices, there was no significant difference between them in establishing putting aim points, except on complex putts of two or more breaks (Hill, 1999). This indicates a floor effect where expert superior performance is not evident until putting situations require more extensive analysis.

One interesting finding was that both experts and novices tended to “under read” the great majority of putts by half of the actual break as measured by a ball rolling device (Hill, 1999). This effect was also found by a long-term investigator of golf putting (Pelz,

1989, 2000), who also determined that experts compensated for the under-read by actually setting up and stroking the ball to the true aim point.

In another putting task, Hill (1999) showed that experts exhibited greater accuracy and consistency in putting. In a 25-foot downhill right-to-left putting situation, experts averaged 40 cm closer to the target with less variability. However, the directional differences were considerably smaller than the differences in distance.

The evidence from the pre-shot routine, mental imaging, occluded vision and consistency studies provide some interesting but inconclusive evidence of the mediation of mental representations in golf putting. Since the literature is limited and the results inconclusive, it appears that understanding the mediating factors and representational use in golf putting will require significant further study using new avenues of investigation and occluded vision tasks supported by concurrent verbal reports.

The Current Study

Putting in golf is one common skill in which accurate and sophisticated mental representations are essential for most putting situations. The current study has been designed to extract individual differences in the mediating effects of mental representations on participants' golf putting performances. As reviewed earlier, mental representations provide one's basic concept of domain tasks and serve as the basis for reasoning, planning and goal determination necessary to determine the estimated ball path and the aim point toward which a golfer putts the ball (Ericsson, 2002a; Hill, 1999). In addition, one's mental representations guide the golfer's neural motor execution of the putt (Ericsson & Lehmann, 1996, Schmidt & Lee, 1999).

Inaccurate putting performance can be attributed to inconsistent motor execution or poor reasoning regarding the predicted ball path and aim point determination and applied stroke force. The first is the result of ineffective motor control and the second results from poorly defined mental representations guiding a golfer's reasoning. Poor motor control results in inconsistent club-ball contact and consequent variable outcomes, even when the golfer is trying to replicate the same shot several times without feedback of the outcomes. Poor reasoning and analysis is a result of inaccurate or incomplete representation of the current putting situation and/or the selection of inappropriate goal targets and aim points/direction.

This study will initially determine the participants' motor control in stroking the golf ball. How the ball is struck by the golfer is not as important as his/her consistency in duplicating the stroke. For example, PGA Tour player Billy Mayfair "slices" his putts (comes across the ball imparting a spin), making the ball move from left to right. Nevertheless, he is highly consistent in his stroke. He simply adjusts for the spin induced break in determining his aim point. Determining that our participants can produce consistent results on putts requiring minimum reasoning and planning will support predictions that differences in accuracy are largely caused by erroneous reasoning and planning based on less refined or incomplete mental representations.

If the putting situation calls for a perfectly straight putt, reasoning beyond recognition that the ball must be rolled directly at the target is removed from the task. [Note: The chances of a perfectly straight putt on a green are infinitesimal at best and therefore are a theoretical concept only. Since this study is conducted on actual golf greens, the tasks requiring straight putts will be set up with minimal break. The important information will be the consistency with which a golfer duplicates his/her putts.] Also, duplication of the same putt multiple times under occluded-vision conditions minimizes any heuristic analysis of force required after the first putt. It must be noted that even if an elite golfer were able to duplicate his/her stroke perfectly, the results may still differ due to continuing changes in the green's topography.

The first task after warm up was a putting task requiring only a basic level of reasoning and planning. In a relatively straight/direct putting situation, the participants were asked to stroke multiple putts to the target, an initial 10 putts without visual access to the target followed by 10 putts with visual access (see Figure 1). The consistency of the golfers' putts revealed their level of motor control in that direction was obvious and distance was attempted by attempting to match the previous putt in the occluded condition. If it is established that they are able to show consistency in their putting stroke, individual differences in more complex subsequent tasks will be considered to be a result of reasoning, analysis, planning and set up based on their mental representations of the goal, the current situation and the basic golf putting task. At two feet, professionals under tour competitive conditions make well over 90% of their putts (Diaz, 1989). According to Dave Pelz (2000) the optimum distance a ball should roll past the hole (giving it the best

chance to fall in) is 17 inches. Thus, 2 to 2 ½ feet laterally from the target is considered to be consistent putting for our participants.

Once consistency has been evaluated, a more complex putting task will be employed to understand differences in cognitive aspects of “reading” a green (analyzing the putting situation), establishing a mental representation of the putting situation and then executing putts based on verbally described alternate target positions while vision of the putting situation is occluded.

As noted earlier, successful putting results from the precise confluence of three variables: force estimate (distance), estimate of direction, and stroke execution. By establishing each participant’s ability to putt consistently in the straight putt tasks, stroke execution can be minimized as a significant variable. The purpose of the complex tasks is to test the ability of expert and novice participants in putting performance based on their mental representations of the putting situations. By occluding the target and topography of the putting situation, this study will examine the participant’s ability to rely on mental representations to guide his/her actions. The accuracy under these conditions will provide evidence of the acuity and accuracy of the participant’s representation mediating the putting performance.

The second putting situation is more complex, encompassing considerable topographical vicissitudes that require intricate reasoning and analysis to envisage the correct ball path and select an accurate aim point (see Figure 2). In addition, the complex topography created changes in speed that made the determination of the necessary stroke force very difficult. The participant was able to study the putting situation and visualize an estimated ball path. When the read was complete, a screen was placed in front of the ball, effectively blocking visual access to the target and the terrain to be traversed. The subject was then given a verbal description of an alternate target location in terms of distance from the original target (e.g. the alternate location is 3 feet to the left and 3 feet past the original target). The participant is then asked to set up and putt to the alternate target. In order to putt the ball accurately, the participant must then use his/her mental representation of the putting situation to relocate to the alternate target, establish a mental aim point, set up and finally putt to the new target.

As established in the direct putting situation, all participants are able to stroke the ball in the target direction with acceptable accuracy. On a flat putt, the aim point and the target are the same. Since all putts are essentially straight putts (toward the aim point) the same stroke is performed for all putts. Thus the critical variable is the aim point derived from the golfer's reasoning and planning based on his/her mental representation of the predicted ball path.

In order to measure the differences, if any, between representational versus visually based performance, the last task of this study will test a modified version of the second task, where participants have visual access to the putting situation. Again, the target of each putt will be designated by the investigator in a rotating manner similar to the occluded task.

The purpose of this study is to show that representative tasks in golf putting produce individual differences between expert and novice golfers and to determine the mediating mechanisms that produce the performance differences.

Based on the constructs of expert performance theory, this study presents the overall hypothesis that experts will show greater accuracy and less variability in all tasks, though novices will indicate an ability to be relatively consistent when only minimal analysis of the direct putting situation is required to determine an accurate aim point. As noted earlier, consistency within two feet (61cm) left and right of the target will indicate the participant's ability to predict his/her stroke direction.

In addition to the overall hypothesis of expert superiority when compared to novices, the construct of mental representation mediation of performance suggests the following hypotheses of performance on the representative experimental tasks in this study.

- Experts will show superior average accuracy on all tasks as measured by distance (cm) from the target.
- Expert putts will result in smaller average differences in distance measure (cm) from the target, as a result of many more hours of deliberate putting practice. It is known that experts take fewer putts per round than novices, and thus are better putters (PGA statistics: see PGATour.com). Also the shorter

the distance from the hole, the more putts are made (Diaz, 1989). Expert putt results are thus expected to be closer to the hole on average than novices.

- Since both experts and novices are not trained in putting under occluded conditions, it is predicted that experts will be more accurate under occluded conditions, which will lead to an interaction with skill and condition.
- Experts generally evaluate a larger area of the green than novices. It is therefore predicted that they will have a finer concept of the relocated target's topographical situation and thus be able to more accurately predict the actual ball path to the target. A canonical correlation of the distance and direction coordinate points in relation to the coordinate points of the relocated targets are thus hypothesized to show that experts' putt coordinates will more closely approximate the relocated target coordinates pattern than will the novices' coordinates.

Understanding the cognitive activities occurring while performing the various tasks might be enhanced over direct observation and performance results. Both concurrent and retrospective verbal reports of participants' thoughts were recorded as they performed their tasks. These will be reported in a later paper. Also, questionnaires were used to elicit past and present performance results, participant demographics, golf putting knowledge and participants' ability to predict ball paths.

In sum, the representative tasks in this study will allow for expert performers to repeatedly exhibit their superior putting skills (Ericsson & Smith, 1991). The study accounts for participants' golf putting backgrounds and knowledge and their ability to consistently stroke a golf ball at a target in a representative golf putting setting. The differences elicited in representation based analyses will establish support for the mediation of mental representations in putting performance.

METHOD

Participants

Following the “expert-novice” framework, a total of 36 golfers, 18 experts and 18 novice golfers participated in the study. The “expert” golfers used in this study were highly skilled club professionals, professional golf management students or university team members. They would not be considered world class golfers such as those participating as PGA Tour professionals, but are in the top 8% of US golfers (eyespy golf, 2007). This study’s golfers were considered experts if they have a registered USGA handicap of 5 or lower (see USGA, 2005) or participate in sanctioned tournaments with no handicap.

The “novice” golfers were selected based on a handicap of 20 or more, or if their five most recent 18-hole rounds averaged 95 to 120 strokes. This golfer level would be considered average or intermediate golfers making up approximately 60% of US golfers (eyespy golf, 2007) . Some novices did not know the scores of their golf rounds but thought they were in the general range defined by a 20+ handicap. Expert and novice golfers were individually contacted and recruited from university golf teams, assistant club professionals, professional golf management programs, university golf classes, and selected local golfers. Based on informal questioning it was noted that the less skilled golfers have played far fewer rounds than the expert golfers.

Participants were evaluated on different days on an outdoor practice putting green, therefore, an expert and novice pair were always run together on the same day and evaluated as matched-pair samples in analyses that might be influenced by the environmental conditions of the day. In order to maintain approximately equal conditions for each participant, golfers were scheduled on or after 10:00 a.m. to insure the morning moisture had dried and that the greens had been recently mowed. There were no cases where rain differentiated the conditions for each pair of golfers.

General Procedure

When the participants first arrived, they were asked to complete a consent form explaining the study and participation requirements. Then they were given a questionnaire about their golfing experience, golf knowledge and putting skills. Due to

time availability, participants were asked to complete the questionnaires in the next two or so days, and return them

After the administrative functions were completed, the participants were instructed in providing verbal protocols and were outfitted with a digital recording device and lapel microphone. Then, the participants were directed to take several putts on a different, but equivalent, line in order to get a "feel" for the green that day and for providing concurrent verbal reports.

When they were comfortable with the exercise and had a feel for the green, the investigator explained the experimental tasks to be performed (a detailed explanation of the tasks are included in the task procedure section below).

The first experimental task was designed to determine the participants' ability to accurately and consistently produce the same stroke. The putting situation was a relatively flat, minimally breaking ball-to-target path. The objective is to duplicate one's putt 10 times with variance as the measure of consistency. The initial 10 putts were executed under occluded conditions with a screen blocking the golfer's visual access to the target and green topography. This was repeated with visual access to the target to detect any effects of occlusion, particular with the distance parameter. As previously discussed, this was intended to establish the hypothesis that golfers with some experience are able to direct their motor system to stroke a ball toward a specific aim point. Once this was established for all participants, individual differences on more complex putting situations could then be ascribed, both to their ability to establish an accurate aim point based on analysis and reasoning of the predicted ball path to the target, as well as to their overall ability to execute the putt.

The second experimental task involves an initial green reading analysis of a complex putting situation with an original target position. This task also incorporated occluded and visual conditions. Upon completing the analysis, a screen was placed between the ball position and the target of the putting situation, occluding the target from the participant's vision. The screen was placed about 2 feet from the ball, giving the golfer little visual feedback on the ball's path or velocity. Instead of asking the participant to putt to the original target, the participant was then asked to putt balls to one of four verbally-described alternate targets while the targets are occluded. By occluding

the target, the golfer was compelled to rely on his/her mental representation of the putting situation in order to accurately relocate and putt to the alternate targets. Therefore, it provided information on the participants' use of mental representations to plan and control performance.

In the visual condition the screen was removed, giving participants visual access to the putting situation. The golfers were able to include a visual representation of the alternate target situation before putting as they would in a normal golfing situation. Differences may reveal how the golfers use their visual information as well as their internal representations. This task also established a baseline for the golfer's normal putting performance.

Some may argue that differences will be influenced by "practice effects" from the second task. It is generally accepted that feedback is necessary for progressive learning (for summaries of feedback effects on learning, see Gibson, Ch 7, 1969 or Maxwell, Masters & Eves, 2003). Therefore, the non-visible location and ball/target green topography of the alternate targets, along with the absence of feedback or knowledge of results in the occluded second task, are unlikely to provide the participants with the necessary episodic knowledge to convert the experience to an understanding of the requirements for the visual task.

Following these tasks, the participant was debriefed.

Materials and Apparatus

The study was conducted on the practice putting green at the Seminole Golf Club, Tallahassee, FL. All participants provided their own putters. Ten Titleist golf balls, originally from a single new set and checked for balance, were provided to all golfers. Marker flags were used for marking the "hole" locations (original targets). Colored plastic golf markers were used as markers for the putting situation layouts and results, and a chalk line was used to mark the ball-target line and perpendicular markings for designating results. A metal tape measure with a centimeter scale was used to determine ball-target and ball-reference point distances (cm) for each putt.

A screening device was fashioned from a temporary coat rack on wheels and sheer black fabric wrapped around the base and over the hanger bar and was used to occlude the participant's vision during the occluded vision tasks.

Design

This study was a matched-pair (SPSS repeated measures) design between highly skilled (expert) and less skilled (average) golfers. It explored cognitive differences in the ability to mentally represent golf putts, mentally move the target position as directed and then putt to the relocated targets while vision was occluded. The independent variables were expert vs. average golfer results, occluded vs. visual execution and four alternate target comparisons. The distance between the target point and the actual putt location (in absolute distance and x- and y- coordinates) were the dependent variables. Expert and average golfers were defined in the "Participants" section above. All target points and actual putt locations were measured in centimeters as polar coordinates and then transposed to x- and y- coordinates to allow for analysis in distance and direction.

Since we must test the subjects on different days there are minor changes in the putting situations from session to session. An attempt was made, however, to duplicate the course each day as closely as possible.

The observed putting results of the participants will validate the golfers' skill levels.

Setup Procedure

After the green was mowed in the morning, the investigators marked out the "putting situations". For the occluded section of the direct putting situation, the target and ball position markers were positioned on relatively flat, level green turf so that the ball path would be as straight as possible. In fact there was a small left-to-right break with a slight uphill bias. The visual condition of the task was the same as the occluded condition but with the screen removed.

The occluded and visual complex tasks were topographically irregular (two to three breaks) in order to avoid a floor effect of putt difficulty between experts and novices, as was experienced in Hill (1999). Putting situations were replicated as closely as possible from session to session using stationary objects near the green and/or previous markings.

The target and ball positions for both tasks were positioned 23 feet apart and denoted with ball markers. This distance was chosen because clearer differences in putts required are evidenced across the handicap spectrum (Fairweather & Sanders, 2005). In

addition, it allows for more topographical variation for the golfers' analyses. A chalk line was laid on the ball-target line and then a 90° cross line chalk marked (determined with a triangle). The four alternate targets were marked, with one in each quadrant (e.g. from original target: 5 feet long x 5 feet right; 3 feet short and 3 feet right; etc.).

Both the occluded and visual tasks used the same complex putting situation (Figure 2). Markers were numbered and pre-sorted so that each putt ball could be marked exactly as it finished. Different color markers were used for each task.

A five foot by three foot screen on wheels, as previously described, was assembled for use in the occluded vision tasks.

Procedure for Experimental Tasks

After the participants completed the preliminary steps, they began the initial direct putting task. As noted above, the first task is a level putting situation with minimum lateral ball movement from origination to the target. When the golfers read the green, they could visually observe that the putt was relatively straight and flat. Most reported the slight left-to-right break. Then the screen was placed to block their view of the target and they were asked to stroke the ball to the target. Without feedback, they were then directed to duplicate the first putt nine more times from the same ball position. Each putt was marked in order at the point it crosses the target latitude and at the final resting position. At the end of the experimental session, all markers were measured as polar coordinates from the target for later transformation into x and y grid coordinates (Figure 5). That is, each putt marker was measured to the target and to a preset reference point, with the third leg being the distance from the target to the reference point. The x - and y -coordinates (x,y), based on the intended target location (0,0) were determined using polar coordinates and then transposed to a normal grid using the Law of Cosines.

Immediately after stroking the each ball, participants were asked to predict where the ball finished. Following the occluded task, participants were instructed to putt 10 more ball, but with visual access to the target. Results were marked and measured as before.

For the occluded complex putting situation, participants were asked to “read” the putting situation with a ball and a small flag defining the putt. They were told to envision that they are putting for the U.S. Open championship and to read the green as if the

tournament rested on this one putt. They were instructed to attempt to have the ball stop at the target so that it will just drop in if the direction is correct. The first putting situation was initially sharply left and uphill then sloped away from the golfer and broke significantly to the right. The green is relatively fast with an estimated Stimpmeter™ rating of approximately 10 (estimated by the head club professional based on previous Stimpmeter readings). The participants were asked to provide concurrent verbal reports while they read the green to capture their conscious focus as they “read.” Then the screen was placed so that the participants could not see the putting situation except for the ball position.

After reading the putt, the participant was advised that he/she should refocus on a verbally described alternate target that is x feet lateral and y feet longitudinal from the original target. They were told to mentally envision the new target, represent an aim line/direction to the target and execute the putt.

Immediately after stroking each putt, the participants were asked to predict where the ball would stop (e.g. long and to the right of the envisioned target). After each putt they were given a new set of alternate coordinates as the new target. Each of the four alternate targets was designated five times in an irregular (random like) order. This was similar to actual golf situations where the golfer is always hitting a “first putt.” Maintaining representations of each target, while putting at another target, typically caused some interference, so the golfer generally returned to the original target and adjusted from there. Twenty rotating putts were taken, five at each alternate target. The rotation was set in a non-sequential order in order to avoid anticipation and have the participant plan each putt individually.

The visual condition repeated the occluded condition, but with visual access to the specified targets and were rotated in a different order. The results of this task acted as a baseline for each participant and indicated how feedback affected their consistency and accuracy.

RESULTS

Overview

Analyses were based on the distance from the ball to the various targets and the x and y coordinates of the ball in relation to the target (see Figures 1 & 2). The ball-target distance represents the ability of the golfers to mentally derive the direction and force necessary to stroke the ball to the target with a chance to fall in the hole or leave a high-percentage second shot close to the target (Ericsson, 2001a; Diaz, 1989). Since the golfing objective is to putt the ball as close to, if not in, the target hole, this measure is the best indicator of domain relevant putting performance (Ericsson & Smith, 1991). Golfers' mental representations of putting situations are theorized to be their bases for analyzing, planning and executing putts (Ericsson, 2001b; Ericsson, 2003).

In addition to the direct distance from the ball, lateral and longitudinal measurements (x and y coordinates) of putts in relation to the opposing axes were also derived from all putting situations in order to ascertain the effects of the participants' distance and directional representations in putt results. Without their having visual access to the designated target (occluded condition), it was not possible to determine an exact target focus of each golfer. It was thus necessary to establish a method of defining their focus from observable results. Since there was no feedback to the golfers on their results, they could only trust that their original representation of the target was accurate and putt to that visualized point. In that all golfers exhibited an average or above level of accuracy, the centroid of the putts to each target (minimal total variance from the centroid) was determined to be the best observable evidence of their target representation. The average of the coordinate points of each golfer's putts in the occluded tasks is considered a meaningful measure of the participant's target representation.

Task Analysis

This study incorporated two putting situations, each including an occluded condition and a visual condition. The first, putting to a single known target, was a straightforward 23-foot putt that broke slightly from left to right (Figure 1). Tasks were performed under both an occluded and visual conditions and allowed for additional participant familiarization with the green and a determination of the ability of the golfers

to stroke the ball in a competent manner. It also allowed the golfers to read and represent the specific putting conditions, and in turn, use their mental representation of the current situation to analyze and execute their putts.

The second was a *complex* putting situation, also with an occluded and visual condition, but with more complex double breaks and undulating topography (Figures 2 & 5). These tasks were designed to provide a level of difficulty that would allow experts the opportunity to demonstrate superior putting acumen and more refined representational mediation.

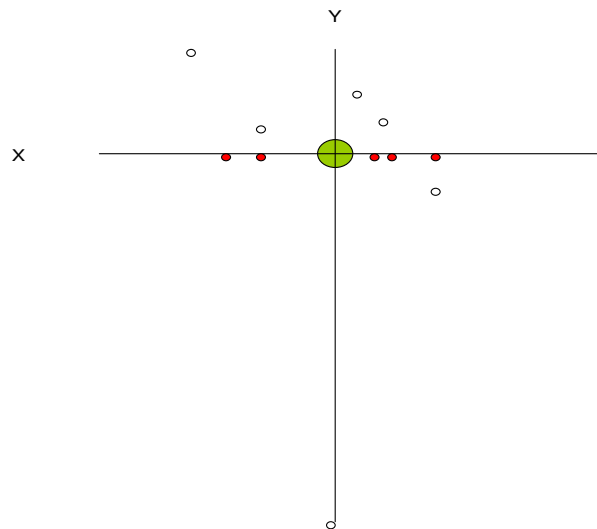


Figure 1. Initial task to ascertain participants' ability to execute a putt toward their aim point.

The analysis of results will first examine the direct putting situation under occluded and visual conditions, to determine the participants' basic putting skills and then continue with the more complex putting situation to reveal higher level representational issues.

Putting With a Single Known Target (Occluded and Visual Conditions)

Analysis of difference between target and end point of putt. As noted earlier, the objective of a putt is to have the ball drop in the target hole. Barring that result, a golfer wants the ball to be close enough to the hole to provide a high percentage chance

at making the next putt. Therefore, the most relevant outcome of a golf putt is the distance between its end point and the cup (ball-to-target distance).

As predicted, an ANOVA of the ball-to-target distance (Grand Mean (GM) = 112.85), using novices and experts performing the task on the same day, revealed reliable main effects for skill ($F(1, 36) = 26.73, p < .01$) and for the visual condition ($F(1, 36) = 42.53, p < .01$). Experts' putts had, on the average, a shorter distance to the target than novices' putts and putts were more accurate in the visual condition compared to the occluded condition.

There was, however, no significant interaction between skill and condition, thus rejecting one of the hypotheses. Both groups performed better in the visual condition (Expert: $F(1, 36) = 20.3, p < .01$; Novice: $F(1, 36) = 17.26, p < .01$).

Finally, it is interesting to observe that the experts' mean *occluded* performance was only 6 cm (2.4 in) farther from the target than the novice mean *visual* performance. This is only about one half the hole diameter and thus directly comparable. The expert putting performance in the occluded condition was at an average level for normal golfer with full visual access.

As expected, experts performed at a higher level than novices on the ball-to-target measures and novices performed better in the visual condition than in the occluded condition. Contrary to predictions, however, experts also performed better in the visual condition to a similar degree.

The next section will examine the two main components of a putt: direction and distance. Direction is reliant on the golfer's ability to visualize and represent the correct ball path, while the distance is a function of internalizing the perceived and represented length of the putt developed during the 'read,' and then utilizing internal representations to guide and control the motor system.

Direction and distance (x and y) coordinates. The x - and y -coordinates defining the end point of each putted ball permit us to measure how much the golfer was short or long and left or right of the intended target. As shown in Figure 4 the target is represented as the origin ($x = 0$ and $y = 0$) from which the average endpoint across a series of 10 putts (without feedback) may be considered the golfer's mental representation of the location of the target in the occluded condition. The x -coordinate of a putt reflects the putter's

ability to establish the correct direction (including any necessary corrections for breaks the ball will take on the way to the target) and the y-coordinate indicates the golfer's ability to stroke the ball to roll the correct distance. As shown in Figure 2, the measurements were given a positive sign if they were to the right of origin and beyond the target with negative values ascribed to the opposite positions.

A MANOVA, with the occluded and visual conditions and skill as independent variables and x and y coordinates for each putt as the dependent variables, revealed a significant skill*condition interaction for the x -variable ($F_{S*C}(1, 72) = 8.55, p = .005$) and a significant main effect of skill for x but not for y ($x: F(1, 72) = 25.90, p < .01$). For the single target situation the putt was selected to be relatively direct or straight. Under

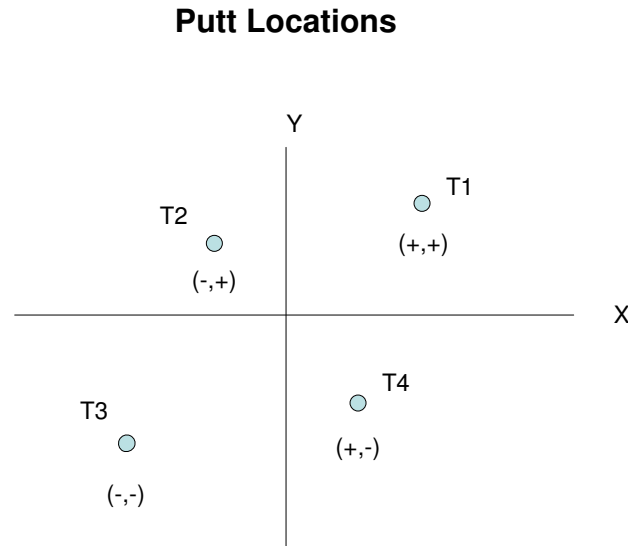


Figure 2. Alternate Target Locations and Arithmetic Nomenclature

those conditions the interaction between level of skill and condition is a confirmation of the predicted expert superiority in the occluded condition for the direction of putts (x -coordinate). As shown in Figure 3 there was no reliable difference for experts, but there was a significant difference between occluded and visual conditions ($t_{\text{cond}} = 5.15, p < .01$). The results showed the majority of the participants erred to the right of the target, largely due to the slight left to right break and the decreasing velocity of the ball exaggerating the final movement.

As predicted, this finding supports the hypothesis that experts' representations in the occluded condition mediated more accurate putts than novices, but only a small difference (11.5 cm or 4.5 in) in the visual condition.

The distance (y) differences between experts and novices were non-significant. The results for the y -coordinates results were not predicted especially as the variance in distance (y -coordinates) is generally considered much more difficult to control and thus produces wider margins for experts to exhibit significant superiority.

One explanation for this failure to find differences may be the results of the averaging procedure. Very long and very short (also left and right) putts can, when aggregated, produce seemingly accurate over-all means, while a set of slightly

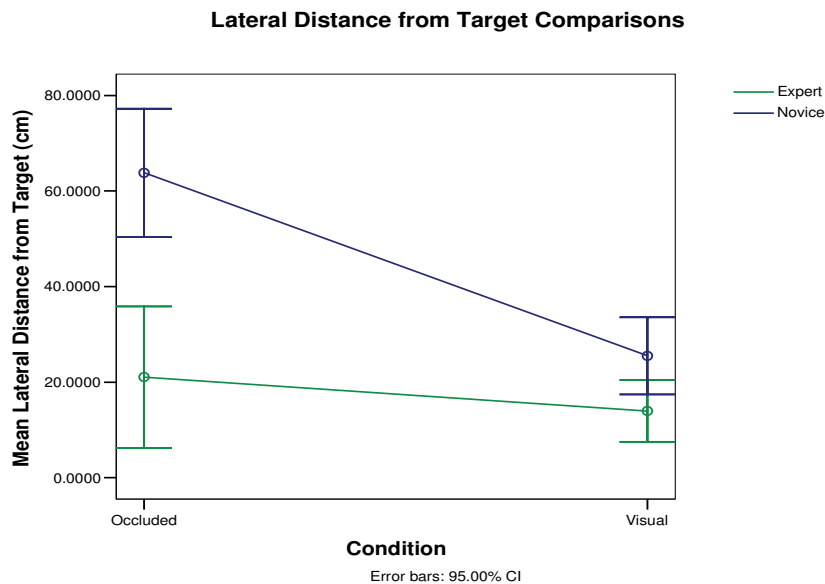


Figure 3. Occluded Skill Differences in Putt Direction (cm)

long putts just past the target might indicate less accuracy. For instance, a MANOVA of the absolute values of x and y distances indicated significant skill and condition differences in both the x and y variables (Skill: $F_{lx}(1, 72) = 40.80, p < .01$; $F_{ly}(1, 72) = 19.48, p < .01$ and Condition: $F_{lx}(1, 72) = 42.81, p < .01$; $F_{ly}(1, 72) = 20.48, p < .01$). In addition, as in the direction/distance results above, there was a skill*condition interaction in the lx directional results ($F_{S*C}(1, 72) = 8.99, p < .01$). If only the absolute distance to the target is considered then experts showed superior distance control. Interestingly, more experts than novices were short of the target line in the occluded condition, while novices

were short more often than experts in the visual condition. This could mean that experts are more likely to achieve their goal of going just past the hole when they are able to use visual perception to heuristically estimate “more or less” force.

This supports the argument that the mental representations of the experts were more refined in that the novices were 34 cm (> 1 foot) farther away from the target in the occluded condition than they were in the visual condition, while the experts were only 11 cm (4.3 inches) closer in the visual condition -- a difference that is roughly the same as the diameter of the hole.

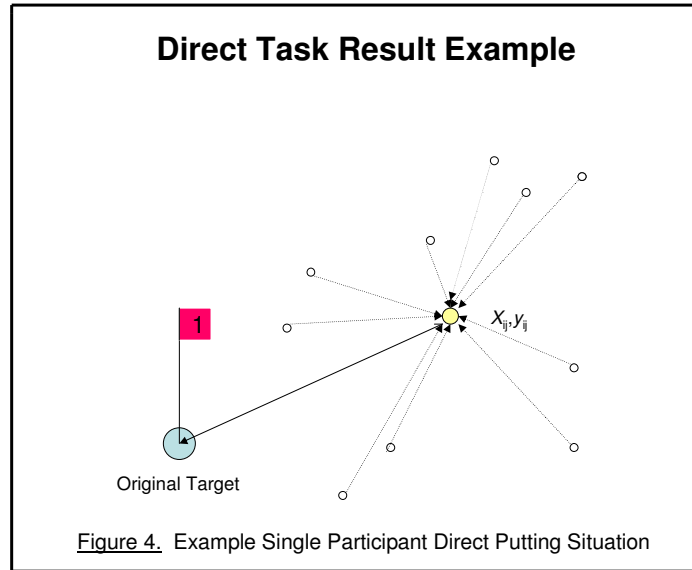
Up to this point, we have seen superior, but anomalous, results by experts and visual condition superiority by both experts and novices. To further clarify these results, the next sections evaluate the variability between consecutive putts within subjects to measure the consistency of performance, a characteristic of many areas of expert performance (Ericsson & Smith, 1991).

Variability of consecutive putts by the same golfer. To examine the consistency of the golfers’ consecutive putts toward the same target, the average x and y coordinates for the series of putts by golfer (i) were computed and were referred to as x_i and y_i . When golfers try and stroke the ball to a single envisioned target in the occluded condition, and the location (x_i, y_i) is the point that minimizes the squared distance from their individual putts--this centroid point is considered to be the best estimate of each participant’s represented target focus (see Figure 4). From this mean, (x_i, y_i) the distance to each golfer’s putts in the series was calculated as a measure of variability.

Comparing the mean distances, a skill-by-condition matched ANOVA ($GM = 74.90$) showed a significant main effect of skill ($F_{\text{Skill}}(1, 36) = 72.76, p < .01$), but no main effect of condition and no interaction between skill and condition. The expert golfer’s average mean distance (53.62 cm) to their individual mean (x_i, y_i) was approximately half the distance of the average novice mean (107.66 cm) in the occluded condition ($t(17) = 5.02, p < .01$), demonstrating greater consistency and precision by the higher skilled players.

The lack of significant differences between conditions indicates that the golfers putted with the same level of consistency toward their target focus, whether they had visual access or not. Because the golfers visually established the target position prior to

their vision being occluded, their mental representations were based on their original green reading. The lack of feedback after each putt insured that they continued to putt to



the same visualized target in the occluded condition. When they had visual access, they continued to putt with the same level of accuracy and consistency. This indicates that their mental representation of the putting situation was relatively constant between conditions and that the visual feedback afforded in the visual condition had no significant influence on their putting stroke consistency.

Individual mean (x_i, y_i) -to-target distance. Based on the reasoning that each participant's mean, (x_i, y_i) indicate his/her represented target location, it was predicted that more refined representations of the actual target would allow the expert golfer to more closely approximate the actual target than the less refined representations of novices. The mean distance from each participant's mean coordinate point (x_i, y_i) to the relocated target coordinate point was predicted to show a reliable expert advantage. This would indicate a more accurate representation of the putting situation and the verbally described target location. A matched pair ANOVA ($GM = 76.16$) did show a significant main effect of skill ($F_{\text{skill}}(1, 36) = 5.22, p < .05$) as well as superiority by both skills in the visual condition ($F_{\text{cond}}(1, 36) = 53.15, p < .01$), but no skill*condition interaction. These results, showing an average 2 foot difference for experts and an almost 3 foot average difference

by novices from the occluded to visual conditions, indicate that all participants had some difficulty in properly representing the target position in the occluded condition. However, once they established their represented target position, (x_i, y_i) , experts showed superior consistency in putting to that represented target position.

Putt progression analyses. It was expected that in the occluded condition both experts and novices would continue to attempt to putt to the same visualized target in that they had no feedback to indicate any necessary adjustments (other than a kinesthetic indication of a miss-hit). In contrast, in the visual condition it was predicted that the participants would improve as they advanced through the ten putts since they could see the results of their putts. A matched ANOVA of the ball-to-target distance showed a significant main effect of skill ($F(1, 340) = 104.78, p < .01$) and condition ($F(1, 340) = 141.90, p < .01$) but no main effect or interactions involving putt progressions. Tukey post hoc comparisons of putt order number showed no significant differences. In both conditions, experts showed no significant differences in distance from the targets as they progressed from their first to last putts. Novices did show an increase on their last putt compared to their putt average in the occluded condition. It may have been only a reaction to being the last putt (golfers were aware that it was the last putt). In the visual condition, novices showed a significant improvement from their first putt to the remainder of their putts ($t(17) = 2.182, p < .05$). These results give some credence to the initial prediction that additional investigation will be necessary to understand the effects of mental representations in mediating successive putting performance.

To golfers, a more meaningful comparison may be the first putt taken, since golf counts all strokes (i.e. no putting “mulligans”). An expert/novice comparison, on the first putt only, shows superior expert accuracy in both the occluded and visual tasks (occluded: $t(17) = 2.525, p < .05$; visual: $t(17) = 3.860, p < .05$). Expert superiority in the visual condition confirms their higher skill level under normal conditions, while in the occluded condition requiring the use of the golfers’ mental representations, the experts’ more refined mental representations mediated their superior performance.

Cross condition performance in distance and direction. The hypotheses that experts would accomplish the putting tasks more accurately than the novices and that novices, but not experts, would be significantly more accurate in the visual condition

were tested. The results for the single target putting situation tasks show putting superiority by the low handicap golfers as predicted, but both skill levels were significantly more accurate in the visual condition than in the occluded condition, most likely from unfamiliarity with occluded putting and lack of feedback.

The results of the direction and distance analyses showed expert superiority in the directional parameter (skill: $F(1, 360) = 103.14, p < .01$; condition: $F(1, 360) = 73.82, p < .01$), and the significant novice improvement between the occluded and visual conditions resulted in a skill*condition interaction ($F_{S*C}(1, 360) = 34.91, p < .01$). This supports the hypothesis that experts' more refined mental representations allow them to more closely approximate the correct ball-to-target path in the occluded condition, while the novices' vaguer representations need perceptual reinforcement to produce more accurate results. In that the determination of the ball's path is more easily relatable to one's mental representation of a putting situation, it supports the hypothesis that experts have more refined mental representations of putting situations and the direction in which the ball must be stroked.

The lack of reliable differences in the distance parameter was contrary to many professional opinions that distance is the most difficult aspect of the putt to control, thus suggesting that experts should be significantly better. Further investigation revealed that experts were, in fact, more accurate in terms of absolute longitudinal distance (closer to hole). In addition, analyses of consistency and accuracy (mean putt distance to each golfer's individual mean) revealed higher expert consistency with their putts, and their ability to accurately represent and putt to an occluded target (each golfer's individual mean to the original target).

Finally, it is noteworthy that experts' occluded putting results were basically the same as novices' visual performance. Thus, despite little or no experience with occluded putting, experts showed a respectable average putting ability when their performance is guided largely by their mental representation of the putting situation.

Next, the analysis will turn to the complex putting situations with more difficult terrain, tougher reads, multiple breaks, occluded and visual conditions and multiple targets. As in the direct putting situations, the first analysis will be the ball-to-target results, then the breakdown of the distance and direction results followed by the variance

of each participant's putts and finally, the putt sequence evaluation. A canonical correlation of all putts will evaluate the overall ability of the participants to address the various targets and provide understanding of the golfers' ability to locate the visually described targets. The complex tasks will be summarized and followed with the general discussion.

Complex Putting Situations (Occluded and Visual Conditions)

Ball-to-target analysis. The ball-to-target distance is the most relevant measure in golf performance. In this analysis, there are four targets to be evaluated in both the occluded and visual conditions. One target is located in each of the four quadrants formulated by the ball-to-target line of the original putting situation with the original target as the (0,0) coordinate (see Figures 2 & 5).

It is important for the reader to understand that the putting situations for each target were purposely selected for their varied ball paths to the targets, and as such, were expected to require a very high skill level to putt accurately with visual access. Once the situations have been screened from view, the difficulty of each putt increases. Thus, accurate putting performance requires very complete and accurate mental representations of the putting situations to provide the basis for relocating the target and for analyzing, planning and executing each putt.

The expert golfers' ball-to-target means were closer to the actual target locations than novice means for all targets and both conditions. Differences in the occluded condition were between 34.0 cm (1.1 ft) on the shortest target (Target 3) to 106.6 cm (3.5 ft) on the longest target (Target 1). In the visual condition, the shortest hole had the smallest expert/novice difference (52.2 cm or 1.7 ft), while the second longest hole had the greatest difference (101.3 cm or 3.3 ft). This is consistent with the evidence that the longer the putt, the less allowance is available for error, thus the less accurate the performance (Diaz, 1989). Less skilled golfers would be expected to exhibit a greater differential.

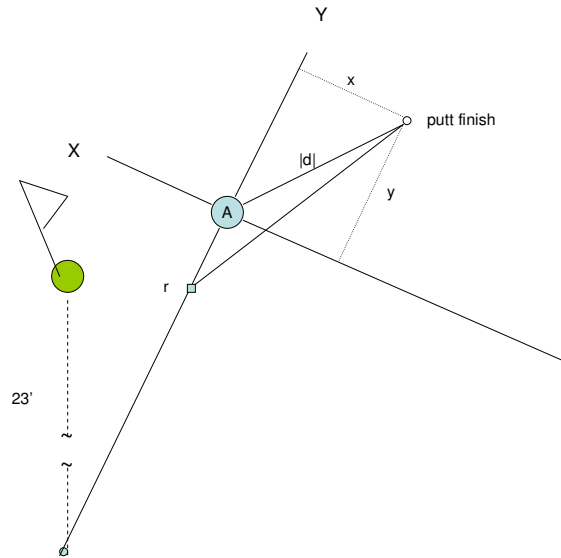


Figure 5. Putting situation layout for expert/novice performance comparisons in complex visual and occluded putting tasks.

Using a matched-pair coupling of participants (Spatz, 2001), a matched-pair ANOVA ($GM = 170.09$) of the ball-to-target distances for four targets in each of the complex situations produced significant main effects for skill ($F(1, 144) = 76.21, p < .01$); condition ($F(1, 144) = 59.09, p < .01$) and target ($F(3, 144) = 43.49, p < .01$). No interactions were found. Post hoc tests by target showed no significant differences between the longer putts (Targets 1 and 2) or between the two short putts (Targets 3 and 4). There were differences between each long putt and each short putt. In that longer putts produce less accuracy in normal putting situations, these results were to be expected (Diaz, 1989).

Although the novices' performance did not differ reliably between conditions on this target, experts' performance was superior in both conditions. Of interest, for Target 2, is that the novices in the visual condition were only 6 cm (2.4 in) more accurate than the experts in the occluded condition.

An analysis of each of the four targets in the occluded condition with matched-pair t-tests showed that experts were reliably superior for the right side Targets 1 & 4 (Tgt 1: $t(17) = 3.55, p < .01$; Tgt 4: $t(17) = 3.06, p < .01$), but only approached significance for the left side Targets 2 & 3. This indicates that there were effects resulting from the topological differences in the two sides of the original ball-target line. Again the

experts' average distance for the left side targets was shorter than the novices' average distance by at least a foot. Experts were reliably superior on all targets in the visual condition.

The distance to Target 2 was 26 feet from the initial ball position and was offset 3 feet to the left and 3 feet past the original target. The ball path initially broke sharply left along and over a rise in the green (total rise approximately two feet) and then traveled a fast moving, downhill track to the right to the target. Both expert and novice putts were heavily bias toward putts that were short of the target (experts: 61 of 90; novices: 70 of 90) and also to the right side of the initial ball-target line (experts: 76 of 90; novices: 59 of 90). The crown of the hill was only 2 to 2.5 feet from the target with the down slope continuing well past the hole. In order to minimize the chance of going substantially past the target, these results indicated that the golfers were tentative in their stroke, leaving the ball short. This minimized the movement to the right after passing the crown since the ball was losing velocity. In some cases the ball never reached the top of the hill and did not have a chance to move to the right. Also, the greater the distance past the target, the more it broke to the right (accounting for the difference between skills in putts to the right of the target). Since the mean absolute lateral distance from the target (x-axis or left/right dimension) was almost identical for both skills and had the largest differential from the target of all the targets, it is an indication that all the golfers had difficulty in representing this putting situation. The fact that the experts more than halved the mean distance to the target in the visual condition (121.40 cm or ~ 4 feet to 56.82 cm or ~ 2 feet), while the novices improved only marginally (121.60 cm or ~4 feet to 111.20 cm ~3.6 feet) suggests that experts preferred to err on the short side, rather than chance a “runaway putt.” Novices on the other hand, are often “timid” and may have had difficulty in representing the required force whether visually accessible or not.

Unlike the other three targets, Target 3 (the other left-side target) ran along the side of the hill, never reaching the crown. The putting situation was therefore a single breaking right-to-left putt that had to be started up the hill and allowed to track down to the target, stopping before it reached the bottom. The ball path was against the grain, which slowed the pace and allowed the putts to avoid running to the bottom of the hill, if it was not stroked with too much force. In their attempt to mitigate this effect, most of the

golfers tended to allow for too much break and finished short and right. The more that the ball traveled uphill and to the right, the less the chance there was that the ball would run back down the hill. Again, but for opposite reasons, there was a strong bias on the part of both skills to be short (experts and novices: 64 of 90 putts) and to the right (experts: 76 of 90 putts; novices: 67 of 90 putts). The grain was somewhat responsible for the short putts, but the worry about hitting the ball too hard and the desire to “err” on the “high side” were also probable contributors. Also, this putting situation with only one basic break was less complex than the other putts and did not require the golfer’s mental representations to encompass as many possibilities in order to establish their aim points.

The lack of specific target reads and precise target locations were conditions that golfers would not normally face. Their superiority on all visual task targets indicates the positive effects these conditions have in reinforcing mental representations under normal putting conditions.

Distance and direction analyses (x and y coordinates). As noted previously, the end point of a putt can be described by the combination of direction and distance to the target. The *x*-coordinate is a measure of the golfers’ accuracy in analyzing and establishing the direction in which the ball must be stroked in order to track to the target under the various ecological and topological conditions. The *y*-coordinate measures the golfers’ ability to analyze the distance and impart the force necessary to roll the ball to the target.

Contrary to the hypothesis, a skill*condition*target MANOVA showed no significant main effects of skill for either direction or distance. Both *x* and *y* measures were reliably different for target ($F_x(3, 288) = 22.86, p < .01$; $F_y(3, 288) = 13.38, p < .01$), while a main effect for condition was noted for the *y*-coordinate only ($F_y(1, 288) = 8.22, p < .01$). In addition, the MANOVA resulted in a skill*target interaction for the *x*-coordinate ($F(3, 288) = 3.127, p < .05$), stemming from occluded expert Target 1 superiority and greater accuracy on Target 2 by the novice golfers (Figure 6). The *y*-coordinates only showed differences between the most difficult long putt (Target 1) and the other targets.

As in the previously reported single target tasks, the complex putt means were determined by both positive and negative designations in these tasks. The methodology

for both single target and complex tasks were basically the same. The means were calculated from the positive and negative measures, and therefore may consist of widely diverse putts and still compare favorably with very accurate putts. As noted in the direct putting situation tasks, when averaged, a putt 10 feet past the target and a putt 10 feet short may indicate accurate putting, while two identical putts ending a foot long would indicate less accuracy.

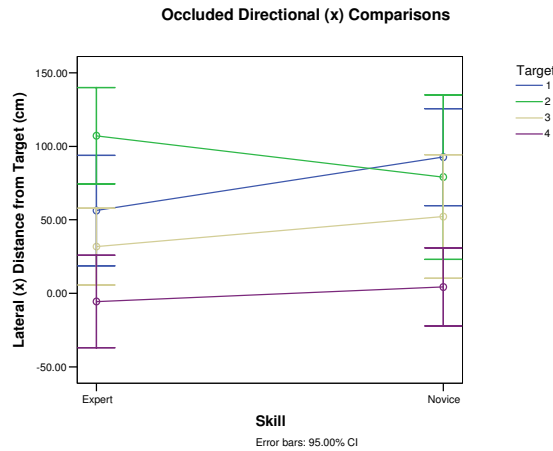


Figure 6. Directional (X) Interaction between Skill and Targets 1 & 2.

An analysis of the absolute values of the x and y measures helps in understanding the apparent contradictions between the coordinate results and the direct distance results. The absolute measures to the relevant axes relates to the golfers' main goal – to end in the hole or as close as possible in both x and y distance from the target. The overall skill \times condition \times target MANOVA analysis did show expert superiority in absolute x and y distance with significant a main effect for skill ($F_x(1, 288) = 9.41, p < .01$; $F_y(1, 288) = 83.54, p < .01$), condition ($F_x(1, 288) = 25.79, p < .01$; $F_y(1, 288) = 29.29; p < .01$) and target ($F_x(3, 288) = 23.16, p < .01$; $F_y(3, 288) = 27.71, p < .01$) and a significant skill*target interaction ($F_{S*T}(3, 288) = 2.90, p < .05$) for the distance (y) parameter. A post hoc analysis revealed that this interaction is related to differential performance of experts and novices for the long vs. short target differences (Targets 1&2: Mean difference = 30.29, $p < .05$; Targets 3&4: Mean difference = 21.89, $p > .10$).

Experts were significantly superior in all mean absolute distance (y) measures (except occluded Target 3) and were marginally closer to the targets in both conditions in the direction (x) measures. The absolute direction coordinates showed no significant differences in the occluded task, but the visual task showed differences in the left side targets and near significance in the longer, most difficult Target 1. This is confirmatory of the concept that distance provides the greatest variability in putting and that experts have acquired more refined heuristic representation gradations translating into more sensitive “feel” for the necessary application of force.

These results are consistent with the claims by golf instructors that the distance of putts tends to be more difficult to master than direction (Pelz, 2000; Wiren, 1991; Woods, w/McDaniel, 1997). Golfers in general can reasonably represent the predicted ball path to the target, estimate a point to aim toward and then stroke the ball toward that aim point (Hill, 1999). Small differences in force, however, can cause a ball to be so short or long that the golfer will have difficulty in making a comeback putt. Distance is gradually learned through heuristic calibration honed through deliberate practice and experience. In the opinion of most teaching pros, extended deliberate practice (which produces refined mental representations) is necessary to become highly skilled at distance putting (Floyd, 1989; Wiren, 1991; Woods, 2001) as proffered by Ericsson et al. (1993).

The distance and direction analyses are indicative, but not conclusive, of expert representational superiority in putting. Superiority is coupled with consistency when ascertaining expert performance (Ericsson & Smith, 1991). In the next section the putting results will be analyzed in terms of variability.

Variability in a sequence of putts by the same golfer: differences in putts to the same target. Expert performance is hypothesized to reflect mental representations that mediate high performance levels on a consistent basis (Ericsson, 2006; Ericsson & Smith, 1991). The following analyses will explore the differences in expert and novice putt variability in relation to their target focus.

For each golfer (i) and target (j) it is possible to calculate the average coordinates (x_{ij}, y_{ij}) of all putts directed to the same target. This mean is the point with the minimal distance (i) to a golfer’s five putts -- each golfer’s best measure of his/her representational accuracy in mentally relocating each target, as verbally instructed in the

occluded condition. As stated in the introduction it was predicted that experts would be able to form more accurate mental representations of the alternate target putting situations. It was hypothesized that the experts' more refined representations of the general terrain of each putting situation would mediate a closer, more consistent pattern of putts and expert individual means would be closer to the targets than those of novices (see Figure 7).

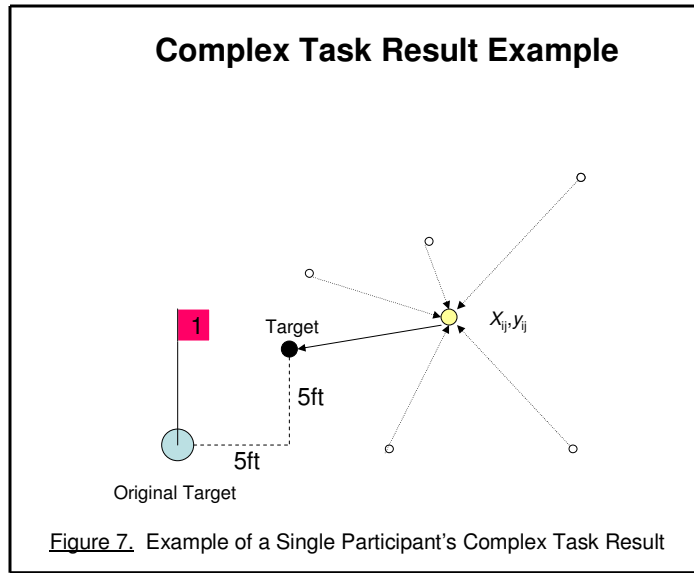
This section will first establish each golfer's represented target from observable measures which, in turn, will be compared to the verbally designated alternate target location (namely the (x_{ij}, y_{ij}) to the corresponding target). Second, the golfer's putt consistency will be evaluated by calculating the distance to (x_{ij}, y_{ij}) of putts directed to the associated target.

An analysis of the centroid (x_{ij}, y_{ij}) -to-target distance by a matched pair ANOVA (GM = 122.07) revealed significant main effects of skill ($F(1, 136) = 29.80, p < .01$), condition ($F(1, 136) = 64.84, p < .01$) and targets ($F(3, 136) = 25.11; p < .01$). There was also an interaction between conditions and targets resulting from the target distance differences ($F_{C*T}(3, 136) = 7.98, p < .01$). Experts' mean centroid coordinates were all closer to the four targets than the novices' in both conditions.

In the *earlier*, occluded single target putting situation, the participants were able to fix a representation of the target location by "reading the green." Based on the analysis of (x_i, y_i) , to the associated target (experts: 3 feet; novices: 4+ feet), both skills exhibited a reasonable ability to represent the target, considering their between and within subjects motor control differences and that the target was 23 feet away.

Conversely, in the *complex*, occluded putting situation, participants were asked to mentally relocate the target and then putt to it. This resulted in a mean distance of (x_{ij}, y_{ij}) to target of approximately 4.6 feet for experts and 6 feet for novices – a foot and a half increase for each skill level.

Experts are expected to be "expert" at analyzing, planning and putting to a target, based on their initial inspection of the putting situation. These experts, who have not been confronted with requirements to mentally relocate a target under occluded conditions, did not exhibit significant high level skill in accurately estimating and representing a specific



measure at a distance of 20 or more feet (e.g. five feet right and five feet long). Although experts were substantially, but not significantly, closer to the directed target coordinates, it is quite possible that, had they had initial access to the target prior to occluded putting, as in the single target tasks, they may have shown greater skill separation. That being the case, the (x_{ij}, y_{ij}) , being the minimum collective distance of each individual's putts, was reasoned to be the best observable evidence of the participants' mentally representation target points or target focus.

Putting consistency. As noted in the previous section, means may be comprised of widely divergent putts and still reflect above average results. An examination of the squared distances between the coordinate points of each of the golfer's five putts per target and their individual mean (centroid) coordinates (ball-to- x_{ij}, y_{ij}) shows their performance accuracy to their target focus as well as sum of squares variability differences between the golfers. The extent of this variability is an indication of the representational refinement differences in each putting situation.

To evaluate each putt-to-centroid squared distance for each target and golfer, a matched-pair ANOVA ($GM: 21725.24$) showed significant main effects of skill ($F_{\text{skill}}(1, 144) = 52.16, p < .01$) and target ($F_{\text{tgt}}(3, 144) = 13.88, p < .01$), and a skill*condition*target interaction. There was no reliable condition difference. As in the

ball-to-target analyses, the long targets and the short targets showed no reliable differences between each other, but the long targets did show significant differences from the short ones, again supporting the evidence that the level of difficulty increases as putt length increases (Diaz, 1989). The overall skill group differences indicated expert superiority, though individually Targets 2 & 3 did not show significant differences. The lack of condition differences indicates that the golfers were using a different target location in the occluded condition, while they could see the actual “relocated” target in the visual condition. The “equality” of their putts to their target focus supports the premise that the golfers putt equally well to the target on which they are focused, although it may not have been the designated target point in the occluded condition.

For most of the targets in occluded and visual tasks experts putts were on the average significantly closer to their mentally represented targets (x_{ij}, y_{ij}) . These results mirrored the ball-to-target results in that the differences on Targets 2 & 3 were not quite statistically significant. As in the ball-to-target measures, the left side targets were not reliably significant, which may be the product of the unique putting situations of Targets 2 & 3. In addition, the anomalous fact that novice Target 2 occluded results were closer to their centroids than in they were in the visual condition affected the total results. Overall, however, this established greater expert accuracy as well as less variability in their individual putts.

Even though targets 2 & 3 did not individually show significant skill differences, when the golfers’ putts to centroid distances to these targets were combined in a single analysis, reliable skill differences in consistency of putts to (x_{ij}, y_{ij}) were realized ($t(34) = 2.30, p < .05$). This results from the near significant levels of expert superiority in the separate targets and the additional power of the analysis. As explained earlier, this skill effect was also achieved for the ball-to-target measures and the distance of (x_{ij}, y_{ij}) to the associated target. The non-significant (5.6 in) difference between conditions in performance for experts on Target 2 indicates representational consistency, whereas the significant *occluded* superiority between conditions of the novice putts may be the result timidity or chance, leaving the putt short of the target but closer than the visual putts. As expected, the experts’ consistency of putts to (x_{ij}, y_{ij}) significantly exceeded that of the novices in the visual condition for all target situations.

Further evidence that our golfers' were actually visualizing targets at varying distances from the verbally described target locations was indicated by one-sample t-tests results. The previous discussion postulating that the best observable evidence of a participants' target focus was the average point of his/her putts to the same target. Therefore, significant differences in the golfers' putts to his/her average coordinate point indicate less than accurate mental target relocation. An overall occluded condition t-test showed significant differences from the target ($t(144) = 21.75, p < .01$). Tests were also reduced to separate skill and individual targets, all of which were reliably different with chance probabilities of less than .01. Golfer target foci ranged from as little as approximately a foot from the designated target to nine feet for the experts, while the novices ranged from approximately sixteen inches to eleven feet. Since the "target foci" in the occluded condition are so diversified and inconsistent, the putt variance from each golfer's (x_{ij}, y_{ij}) is a more meaningful indication of performance. In the visual condition, the target could be visually determined, thus the measurements from the target are most meaningful.

The inference that both experts and novices are unsystematically variable between subjects in relocating the targets, as directed, should produce two results. First, expert ball-to- x_{ij}, y_{ij} and ball-to-target distance results, as guided by their more refined representations of the putting situation, should be generally superior to novices as previously demonstrated. Second, participants should have similar ball-to- x_{ij}, y_{ij} performances in the occluded condition to those they exhibit in the ball-to-target measures in the visual condition (i.e. occluded ball-to- $x_{ij}, y_{ij} \approx$ visual ball-to-target). Comparisons between experts and novices have already shown that experts are generally superior to novices in both the ball-to-target and ball-to- x_{ij}, y_{ij} measures, but not to the centroid (x_{ij}, y_{ij}) location in relation to the directed target.

To investigate the second hypothesis that experts will more closely approximate their visual performance in the occluded condition than novices, experts and novices were analyzed separately to compare their occluded ball-to-centroid results with their visual ball-to-target results. The ball-to-centroid measures imply the effect of the golfer's representational guidance to the visualized relocated-target position. The ability to putt as well to their represented occluded target as they putt to the visually available target is

indicative of how effective their representations analyze, plan and guide their behavior in putting.

Each skill group was analyzed between conditions and targets. Experts did show overall differences in condition and target with a skill*target interaction ($F_{\text{cond}}(1, 72) = 4.31; p < .05$; $F_{\text{tgt}}(3, 72) = 22.29, p < .01$ and $F_{\text{S*T}}(3, 72) = 3.45, p < .05$). Novices exhibited a somewhat stronger skill difference as well as target differences ($F_{\text{cond}}(1, 72) = 16.63, p < .01$; $F_{\text{tgt}}(3, 72) = 13.37, p < .01$), with no interaction. The significant expert differences between the conditions were due to the large Target 1 disparity, where the mean ball-to- x_{ij}, y_{ij} distance was 46 cm (1.5 feet) less than the mean ball-to-target distance. All other target differences were within 6 cm of each other. The significant novice results were based on the condition differences in the long putts, while the short putts were within 2/3 foot of each other. These results support the hypothesis comparison for the short putts, while the long putts were expected to show larger variation as a consequence of the distance. The purpose of this analysis was to illustrate the homogeneity of each skill level when putting to any given represented target, either when the target was occluded or when they had visual access. The differences between experts and novices for both ball-to-centroid and ball-to-target distances, remain highly in favor of the experts as shown in previous analyses above.

Finally, by definition, the distance from each golfer's five putts to the mean coordinate point of those putts minimizes the distance to any other point, thus the ball-to-centroid measures will be less than (or at best equal to) the ball-to-target distances. Thus, significant differences between them will indicate reliable differences in the golfers focus points and the actual target. A repeated measures ANOVA indicated significant overall differences between the ball-to-target and ball-to-centroid results ($F(1, 136) = 269.27, p < .01$) and between experts and novices ($F(1, 136) = 43.18, p < .01$). These highly significant differences also support the target focus point argument.

If, in fact, skill in golf putting is determined by the ability to putt as closely as possible to the *envisioned* target, it is of interest to analyze each golfer's putt to their individual mean distances from task to task. In both cases, the result would reflect where the golfers were locating the target and aiming each putt. An ANOVA showed the expected skill differences ($F(1, 144) = 78.68, p < .01$), but exhibited no significant

variance between conditions. Novices did show a reliable difference between conditions for Target 2, but interestingly they were far better in the occluded task than the visual task. This may reflect an advantageous averaging result, or simply an anomalous chance occurrence, in the occluded condition rather than skilled accuracy. All other targets for both experts and novices showed somewhat better but non-significant results in the visual condition.

Visual condition superiority in most of the ball-to-target measures indicate that both skills are better performers when they can verify the target position, however, when the envisioned target in both conditions are compared, no reliable differences between the conditions are revealed.

The variability analyses revealed several insights into representational mediation of putting. Overall we saw expert ball-to-target superiority under occluded conditions when the participants were forced to use their representations to analyze, plan and execute their putts. However, when occluded putting was compared to visual putting, superior performance was noted in the visual condition by both experts and novices. This indicated that the mental representations of the four alternate targets based on the investigator's verbally described coordinates did not accurately approximate the actual target points. It was postulated that the mean of each golfer's five putts at each target (individual mean) represented his/her target focus or the point each golfer envisioned as the investigator described target. Analyses showed that there were no significant skill differences in the x_{ij}, y_{ij} -to-target distance and that there was a significant difference between the individual mean (x_{ij}, y_{ij}) coordinates and the target coordinates. However, when it was shown that there were overall skill differences in putt-to- (x_{ij}, y_{ij}) distance, it indicated that the experts' representations were more effective than novices' in mediating putts to their own visualized targets.

Analysis by putt. Five putts were executed to each of the four targets in a random like progression. The rotation left two to six putts between each target so that the golfer had to refocus on a different putting situation for each putt. To explore the progressive putt sequence relationships to the ball-to-target performance measures, an ANOVA (skill x condition x target x putt sequence) was conducted and it showed significant main effects for skill ($F(1, 1440)=138.49, p < .01$), condition ($F(1, 1440)= 93.36, p < .01$),

and target ($F(3, 1440) = 68.74, p < .01$), but there were no significant differences attributable to the order of putts to each target. As in previous analyses, no differences were noted between the short targets, but reliable differences were indicated between long and short putts, as expected. In addition, a three-way interaction between skill*condition*putt sequence was significant: $F(4, 1440) = 2.416, p < .05$. A skill*putt sequence interaction was shown when only the occluded condition results were compared ($F(4, 720) = 2.82, p < .05$). No interaction resulted from the visual condition comparisons, limiting the overall interaction effects to the occluded condition. Although experts were not significantly closer to the target on Putt 1, the remaining putts widened the difference with novices trending away from the target and experts closer. A skill x putt sequence comparison of the occluded condition omitting Putt 1 shows no interaction, establishing the Putt 1 measures as the element responsible for interaction effects. This is counter to the hypothesis that experts are superior on Putt 1. However, if the target focus of each golfer in the occluded condition is their x_{ij}, y_{ij} coordinate point, putt differences from the alternate target would not be expected to show the effect.

There are no second chances on putts in golf, therefore golfers must rely on their ability to read a green and then make an accurate first putt. Since a putt counts just as much as a 300 yard drive, it is just as important to minimize putts as it is to be long and accurate off the tee.

Overall analyses of ball-to-target distances for initial putts to each target showed reliable differences for skill ($F(1, 144) = 16.50, p < .01$), condition ($F(1, 144) = 18.05, p < .01$) and target ($F(3, 144) = 5.44, p < .01$). Experts were superior on the right side targets while there were no reliable differences or superiority shown on the left side targets. There was a skill*condition interaction ($F(1, 288) = 6.71, p < .05$) indicating visual superiority due to a more detailed representation gained from their opportunity to read the actual putting situation (Figure 8). Novices were almost a foot closer to Target 2 than the experts and were nearly equal on Target 3 in the occluded condition, however these differences were not reliable. The complexities of these two targets were noted earlier and the first putt reflected the same performance characteristics as the mean ball-to-target results.

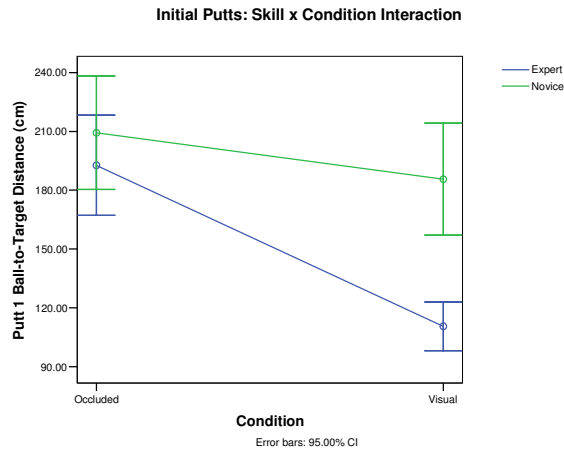


Figure 8. Interaction of Initial Putt Differences to Each Target.

The significant skill differences were actually largely due to the performance in the visual condition. In the occluded condition, only Target 4 produced a significant expert advantage, while Target 4 was the only target that was not reliably different in the visual condition.

Again it is important to recognize that the target focus of the participants was significantly distant from the alternate targets. An analysis of the initial putt distances to the golfers' (x_{ij}, y_{ij}) shows expert superiority and perhaps a better understanding of the skill group differences.

A skill x condition x target ANOVA for the distance of initial putts from (x_{ij}, y_{ij}) showed significant skill and target differences but no differences between conditions (skill: $F(1, 144) = 17.64, p < .01$; target: $F(3, 144) = 9.09, p < .01$). There was no reliable difference between conditions and no interaction. As expected, experts outperformed novices when putting to their target focus and targets showed differences due to the length of the putt.

Relationship of Target Pattern to Golfer Cluster Pattern

As previously discussed, it was reasoned that the participants' target focus in the occluded condition was represented by their mean putt coordinates x_{ij}, y_{ij} (centroid). In the current study, the golfers' centroid locations showed considerable inconsistency in representing the occluded target positions. Although expert centroids were marginally closer to the designated targets on average, the differences were not significant and the

range of the centroid-to-target distances for each skill group was between less than a foot to more than 10 feet. These results show that representing a new target that differs from the original target is not a practiced skill of golfers, either experts or novices. However, the fact that the golfers were unable to accurately relocate the individual targets, does not necessarily indicate that they had no representation of the overall pattern of the target positions.

In order to establish the golfer's represented relations between the four designated targets, each golfer's observed putts were compared to the coordinates of the respective targets in a series of analyses. In that each putt and target location has two coordinates, lateral (x) and longitudinal (y), a canonical correlation was calculated to determine the multivariate relationship of putts to target coordinates.

This comparison compared each golfer's putts' x, y coordinates with those of the target to measure whether he/she was able to distribute their putts in relation to the designated targets. Results showed that each participant's coordinates were significantly correlated with the target coordinates (Mean Correlations: Expert_{Occluded} = .880, Novice_{Occluded} = .872, Expert_{Visual} = .948, Novice_{Visual} = .892).

To insure normal distribution conditions, a *Fisher Z* transformation of the data was analyzed and revealed a reliable skill difference ($F_{\text{skill}}(1, 34) = 6.40, p < .05$) and a skill*condition interaction ($F_{\text{S*C}}(1, 34) = 7.69, p < .01$). The differences between conditions only approached significance (see Figure 9).



Figure 9. Fisher Z Transformed Correlations of Putt Performance

The high correlations indicate that both experts and novices were able to recognize the pattern of target locations and were able to relate their putt clusters to that pattern, however, there was no significant differentiation between skill groups in the occluded condition. There was, however, a reliable difference in the visual condition. Example cluster patterns with target patterns illustrating higher and lower correlations are

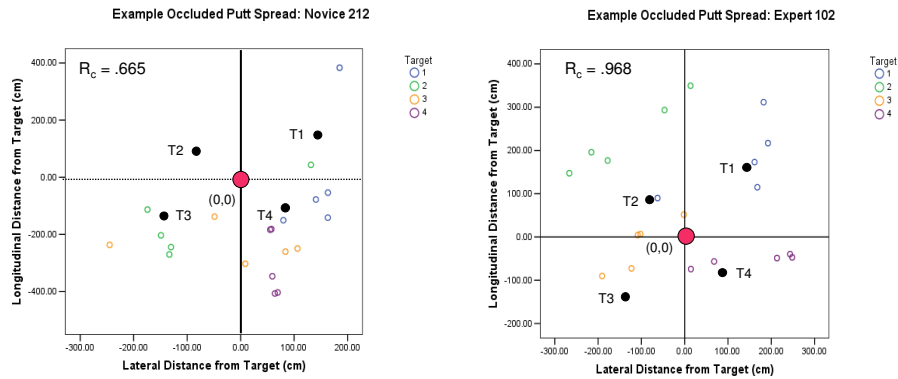


Figure 10. Example cluster spreads of high and low canonical correlations.

pictured in Figure 10.

These results do not support the representational differentiation explanation of the expert performance framework. However, when the direction (x) and distance (y) are correlated separately with the complementary x,y coordinates of the targets, analyses show no significant differences in the direction of putts between skill groups, but robust differences in distance of putts (distance (y): $F_{\text{skill}}(1, 34) = 23.64, p < .01$; $F_{\text{cond}}(1, 34) = 10.78, p < .01$; direction (x): $F_{\text{cond}}(1, 34) = 12.96, p < .01$). In addition, comparison of expert and novice correlations in the occluded condition show no direction differences between skill groups, but significant skill group differences in distance ($t(17) = 3.165, p < .01$). This has implications for different types of putting representations, the knowledge that supports them and the manner in which they are utilized.

These results further support several representational concepts as revealed by the previous analyses. First, these results strongly indicate that neither experts nor novices

are able to accurately represent verbally stated measures and apply them to a situation from a distance of 20 feet or more. For example, the investigator only advised the participants to reset the target to a point that is x feet left or right and y feet long or short (e.g. 5 ft right and 5 ft long) from the originally “read” target location. It was originally hypothesized that experts could use their mental representation of the green to more accurately relocate the target than novices, but the large difference between their occluded and visual results do not support this. However the significant differences in skill group distance performance supports representational superiority in the heuristically determined representation of applied putt force. The absence of a significant difference between the condition correlations of the novices suggest a more general representational difficulty in accurately judging and stroking the ball toward relocated targets in an integrated manner with or without perceptual access to green. Second, the results support the earlier observations that the integrations of experts’ putting toward the different targets in the occluded condition is not reliably different from the integrations of the novices’ performance in the visual condition. Third, the significant difference in experts’ canonical correlations between-conditions correlations, and lack of significant skill-group differences in the occluded condition, taken together indicate that the experts’ predicted advantage in representing targets in the occluded condition was not observed.

In summary, these results indicate that both experts and novices were sensitive to target locations in relation to the other three targets, but that experts were not reliably better than novices in the occluded condition. However, when the putting parameters of distance and direction were analyzed separately, experts showed significant distance superiority. The significant skill difference in the visual condition between expert and novice correlations indicate better putting performance consistency in relation to the targets by the experts.

Performance Relationships with Self-report Indicators

A self-report questionnaire was completed by the participants enumerating relevant aspects of their golf experience. As projected by Ericsson et al. (1993), experts were reliably younger when they first began playing, rated their putting ability higher, reported more one putt greens and fewer three plus putt greens, and practiced more often

than novices. Lower handicaps are a reflection of their current performance level. These can all be considered indicators and/or products of total deliberate practice by the golfers.

The expected expert/novice differences in the participants' golfing histories were then analyzed for relationships with performance. In the occluded condition, significant relationships with the ball-to-target measures on several targets were realized for starting age (T1: $r = .421, p < .05$; T2: $r = .390, p < .05$), handicap (T1: $r = .612, p < .01$; T2: $r = .554, p < .01$; T3: $r = .430, p < .05$; T4: $r = .555, p < .01$), one-putts per round (T1: $r = -.556, p < .01$; T2: $r = -.536, p < .01$; T3: $r = -.415, p < .05$; T4: $r = -.525, p < .05$), three-putts per round (T1: $r = .402, p < .05$; T3: $r = .458, p < .05$; T4: $r = .471, p < .05$), and practice days per week (T1: $r = -.422, p < .05$; T4: $r = -.431, p < .05$). Interestingly, the length of the average putting practice sessions showed little relationship to ball-to-target performance

In the visual condition, experts were reliably more accurate on all ball-to-target measures. Commensurate with this performance, there were significant relationships with all expert performance characteristics (excluding practice time/session) with two exceptions: number of practice days and Target 1 and initial starting age and Target 2 performance. These results indicate a relatively strong relationship between golf putting performance and indices of golf experience and deliberate practice in the more familiar putting condition.

The correlations between performance and experience on Targets 2 and 3 in the occluded condition were somewhat less indicative of the relationship due to the less reliable performance results. However, there were significant Target 2 relationships with three of the experience indicators (handicap, initial playing age and one putt greens per round). Target 3 showed significant relationships with the one putt and three putt per round indicators.

Correlations of the golf experience/deliberate practice indicators with the variance results were less defining than the ball-to-target relationships. Significant handicap correlations were realized for all targets that showed skill differences in variability, however, only Target 1 (the longest target) indicated a reliable relationship with two indicators (one putts: $r = -.500, p < .01$ and three putts: $r = .579, p < .01$) and Target 4 correlated with practice days per week ($r = -.440, p < .05$).

The variance results in the visual condition produced significant correlations with at least three of the experience categories. As was the case in the ball-to-target comparisons time per practice session did not show any significant relationships.

Lastly, the canonical correlation results were compared with the golf experience/deliberate practice indicators with interesting results. As indicated in the golfers' mean putt relationships with the four complex targets, there were no skill differences in the occluded condition, but a significant expert/novice difference in the visual condition. The individual golfers' canonical correlation results showed no occluded result relationships with the experience indicators, however, three putts/round and practice days/week were all significantly correlated in the visual condition. This is consistent with the skill difference results.

Experience relationship summary. The highest occluded correlations were obtained for the reported average number of three-putts per round, average one-putts per round and handicap for the ball-to-target performance measures. The number of practice days per week and starting age were also reliably correlated. The ball-to- x_{ij}, y_{ij} and canonical correlations were less related to the experience/deliberate practice factors, particularly in the occluded condition. These results reflect the greater distance variability in the ball-to-target distance measures.

The greatest correlations with the experience factors were from the most differential expert/novice results, suggesting that the effects of deliberate practice indicated by the experience categories may be significant factors in producing expert performance.

It must be noted that self assessment of putting ability can only be considered as a guide in that experts and novices may not be using the same criteria for assessment. Also, the estimates for one-putt greens per round are not necessarily based on consistent measures since the shots immediately preceding the putts can vary greatly in distance and leave putt lengths that are highly variable.

The visual condition ball-to-target performance significantly correlated with the same reported variables but had generally higher correlation coefficients. This was expected since experts are significantly better putters, as indicated in the previous sections, and

feedback was available for any necessary adjustments. Novices also had feedback, however they would not be expected to be as consistent as experts.

Summary of Results

Results were analyzed in several contexts. First, and most important to a golfer, is the putted ball distance to the target. Overall, as hypothesized, experts were significantly closer to the target than were novices, however, on targets 2 and 3 in the occluded condition the more accurate expert results only approached, but did not reach the .05 significance level. However, when Targets 2 and 3 were combined, experts showed reliable superiority.

Targets 2 and 3 were located to the left of the ball-target line and the delicate nature of the Target 2 putting situation necessitated great precision in order to putt the ball close to the target. Thus, both skill levels were off target in the occluded condition. Target 3 was a more standard putt to read but was also positioned such that it was difficult to accurately represent the putting situation based only on the golfers' reads of the original target. The significant condition differences for each skill group supports this conclusion. Overall, the ball-to-target results indicate representational mediation of performance and superior representational bases in experts.

Secondly, since a putt is a combination of both directional (x -coordinate) and distance (y -coordinate) parameters, these measures were analyzed separately. No significant differences were found in the occluded condition. However, since coordinate means of putt measures using positive and negative annotation can be misleading regarding putting accuracy, we also averaged the absolute distance from the target for each parameter and found expert distance superiority. This is a purer distance measure and golfers would generally prefer to be closer to the target than to be on a particular side of the target. Directional differences were mixed and generally not significant. This is partly the result of the difficulty both skills evidenced in locating the verbally described target coordinates of the alternate targets. These results support the generally accepted judgment proffered by many golf professionals that distance is the key to putting effectiveness (Floyd, 1989; Wiren, 1991; Woods, 2001).

Consistent high performance is a benchmark of expert performance (Ericsson & Smith, 1991). It was hypothesized that experts' individual mean putt coordinates (x_{ij}, y_{ij})

would be closer to the actual target than those of the novices. The experts' x_{ij}, y_{ij} locations were closer to all targets, however, the differences were significant only for the most difficult target (Target 1) in the occluded condition. In that neither experts nor novices are skilled in mentally relocating target locations based on verbally directed measures, it follows that there will be little consistency by either skill group in putting to the designated targets.

The comparison of the mean ball-to-target differences and the mean putt distance to x_{ij}, y_{ij} provided evidence that the participants were not able to consistently relocate the target from the verbally described coordinates as accurately as expected. This was supported by the significant x_{ij}, y_{ij} coordinate differences in comparison to the target positions (one sample t-test, target = 0).

These representational difficulties lead to the analysis of the average putt distance from each golfer's individual mean (Figure 8). The results showed overall expert superiority, but consistent with the ball-to-target measures, two targets in the occluded condition approached, but did not quite reach, significant skill differences. Again the left side putts showed the smallest skill differences. Combining the left side target results did evoke significant skill group differences suggesting that the expert advantage was not individually recognized due to power limitations.

Further analysis by canonical correlation showed a significant skill*condition interaction. The visual superiority of experts in the visual condition, reinforced the evidence that the experts were not "expert" at adjusting the target location, but were superior in putting to their targets of focus. In addition, the strong correlations with the four alternate targets in the occluded condition provided additional evidence of representational mediation of performance.

Analyses showed no effects of putt progression (putts 1-5) on putting accuracy. Interestingly and contrary to expectations, there were no ball-to-target skill differences in the occluded condition on the first putt. In that golf allows no "second chances," expert golfers must maximize their first putt capabilities. In the visual condition, however, experts were superior to novices on the first putt on three targets and approached significance on the last target. This again supports the evidence showing only plebeian

skills in mentally relocating and visualizing the verbally described alternate target locations.

The effects of the occluded and visual conditions indicated that ball-to-target distance results were superior overall in the visual condition for both skill levels. Although it was expected that experts would be able to more closely approximate their visual results in the occluded condition, the difficulty in relocating the verbally described alternate targets in the occluded condition did not allow for a true comparison. In a further analysis using the individual mean measures as their target focus, both skill levels showed no differences between conditions, although experts did outperform novices on most targets and conditions.

GENERAL DISCUSSION

Mental representations acquired by performers in a domain have been proposed as the principle mediators of performance (Ericsson, 2003, 2006; Ericsson, Krampe & Tesch-Römer, 1993; Ericsson & Smith, 1991). If so, the degree of mental representation effectiveness, honed by deliberate practice, is a major determinant of the level of performance.

In order to examine these theories in golf putting, this study was designed to test the golfers abilities to effectively perform in situations where their representations were their only guide to the putting situation, to test the differences between highly skilled golfers and average golfers (“experts” and “novices”), and to show that superior performance was attributable to the application of more highly sophisticated and refined mental representations, at least in a major way.

Putting Performance

The occlusion of visual access after an initial examination of a putting situation, requires that a golfer rely on his/her mental representation to establish a direction and derive the force of the putting stroke. Putting performance under these conditions provides an observable measure of the degree to which golfers can use their mental representations to mediate their putting effectiveness. This measure must then be attenuated by that which can be attributable to mental representation mediation and not by practiced golfer consistency alone.

Screening the golfers’ visual access to the putting situation after they had an opportunity to conceptualize and form a representation of the putt insured that their task performance was based on their mental representation of the situation. In these occluded tasks, expert superiority can reveal more effective mental representations in guiding one’s analysis, planning and execution of the putt. The expert golfer is also highly trained in the physical execution of a putt, and can be expected to be more consistent putting to a single represented point. Thus if the variance is smaller for the expert and greater for the novice, as expected, the consistency of the expert will enhance the differences, and the differential results may not solely be attributable to more refined representations.

It should also be noted that the novices are not total golf neophytes. They were selected based on the handicap criteria of average golfers, from whom would be expected less than 50 putts in a round of 18 holes. Thus, they would average 2.5 to 3 putts per hole or just .5 to 1 putt per hole over par. As such, they indicated a sense of normal green characteristics and generally what to expect from a solidly stroked ball.

On the other hand, the complex tasks added several representational difficulties to the participants' putting performances. First, participants had to mentally relocate the targets based on verbally described measures based on the target location that they originally represented (e.g. 5 feet left and 5 feet short of the original target location). Second, each of the four relocated targets required altered putt analyses and planning based only on their read of the topological conditions related to the original putting situation. Third, the complex putts were all difficult to assess since they each included uphill and downhill variables as well as left and right breaks. Forth, the putts were variously rotated among the four targets, forcing the participants to reassess each target each time. Finally, the golfers received no feedback on the results of their putting efforts, thus they had to continue to rely on their original putting situation representation on all subsequent putts. In the complex situation, this meant retaining the original read for 20 putts, and mentally relocating the targets for each putt. They could perceive some kinesthetic feedback on each putt, but this only informed the golfer about how well he/she stroked the ball and perhaps an indication of whether it was off the intended line or not. This would only allow them to adjust their stroke to better putt to the target that they have represented and not to make direction and distance adjustments.

Each putt under occluded conditions, therefore, must be reevaluated based on the participants' mental representation of the original putting situation and any memory of previous putts to that target. This included resetting an aim point/line, feeling (representing) the force required, and setting up and executing based only on their representation. If the golfers putted to only one target under these conditions, expert consistency to the target would allow one to attribute superiority to a more practiced stroke. However, under the complex occluded task constraints, each putt must be reevaluated based on the golfers' representations and thus superior performance on all

four targets as a total task would be from the effect of superior representations mediating the performance.

Consideration must be given to the participants' lack of deliberate practice in occluded putting which contributed differentially to the putting results and are unrelated to most golfers' normal performance level. In addition, it is important to recognize that the participants' analyses, planning and resulting performance were affected by conditions outside their expertise in the domain. The fact that the participants did not have the opportunity to specifically read the actual putting situations for the offset targets mitigate against normal golf experience. It is also very difficult, and not necessarily within the scope of even a highly skilled golfer's domain expertise, to judge common measures, both lateral and longitudinal, from twenty or more feet away and then mentally establish an aim line and distance perspective with only an inexact notion of the location of the target. As such, allowances must be made for the level of the occluded condition results.

In both the single target and complex putting situations, the visual condition tasks were executed under normal perceptual conditions experienced on the golf course. This condition was used as a control situation and comparisons between conditions indicated the level of effectiveness attained through each golfer's representational mediation.

Many of the effects and findings found in the single target putting tasks are also applicable to the complex putting tasks. For example, the ability of participants to putt in the occluded condition based on their mental representations. Also, the greater variability of the distance parameter vis-à-vis direction found in the single target putting tasks apply as well to the complex putting tasks.

A final observation is suggested by several golf books and observations from professional golfers (Floyd, 1989; Pelz, 2000; Woods w/McDaniel, 1977). The establishment of a putting stroke's force is based on a golfer's heuristically instantiated representation of force required to stroke the ball the perceived distance. Many golfers rely on their "feel" for the putt to hit it the correct distance, and they internalize this "feel" by their original read and perception of the target as they address the ball. The ability to successfully apply the required force to the ball is the result of the gradation refinements incorporated in the golfer's mental and kinesthetic representations. Most

golfers have little or no practice in occluded putting, although many golfers might take a tip from Tiger Woods who has suggested that putting “blind” is the best way to develop feel for distance (Woods, 2001).

This discussion will first look at evidence related to the mediation of the golfers’ mental representations in their analysis, planning and execution of their putting performance. Next, expert/novice differences will be evaluated to establish expert superiority in putting, if any. Finally, the evidence for representational mediation, as opposed to well practiced stroke consistency, will be discussed to establish whether or not the concept of representational refinement can be supported in golf putting.

Representational Mediation in Golf Putting

The overall representational mediation the golf putting task will be discussed first from the aspect of constraints inherent in the study design and then from several evidentiary task results. The main design constraint was the visual occlusion of the putting situations in order to insure that the participants relied on their representation gained from their visual examination of the green (reading the green) prior to occlusion. Once occluded the golfers had to base their aim point/line and distance heuristic evaluation on their internal representation of the putt gained from the “read.”

The tasks involving a single known target (or single target) were designed to not only insure a reasonable level of novice putting competence, but also to support the hypothesis that all participants were able to employ their representation as the basis for putt analysis and planning (setting the aim point and stroke force estimate). The results showed that the golfers, on average, putted within or close to the pre-established competence levels and that the experts were significantly more accurate than the novices. This either attests to effective representational analysis, planning and motor system guidance, or to a more highly developed “motor memory,” or both. A perception-action approach, often posited as an explanation for motor functions, requires either a visual or kinesthetic stimulus to activate the motor system (Williams, Davids & Williams, 2001). Since the target was occluded from sight, there was no visual perception for motor guidance and a kinesthetic stimulus would not explain direction and an unrepresented distance. Thus, the participants had to maintain an image of the target distance, as well as the topography of the putting situation, so that they could mentally re-establish the target

direction and aim point and then set up and putt the next ball. As informally observed by the investigator, many of the participants stepped away and reestablished their aim points and alignments between putts as a reinforcement of their putt plan. Finally, if the participants were simply trying to replicate their previous putt(s), they had to rely on their internal representation of the earlier putting process as their guide.

Ball-to-target relationship. A canonical correlation of the x_i, y_i coordinates with the four complex target coordinates resulted in substantial and significant correlations for both skill groups. This provides a persuasive argument for the golfers' ability to represent the target zone. The four target locations in the complex putting situation tasks were matched against each golfer's ball locations in a four way correlation of the x and y coordinates. The significant, high canonical correlation means of both experts ($r_c = .880$) and novices ($r_c = .872$) in the occluded condition (total range: 0.625 to 0.983) indicated the golfers mental representations of the general direction of the four targets were well located in the described quadrant. This showed that all participants had an effective representational base from which to mediate their occluded putts. Skill comparisons of the correlations will be discussed in a later section.

Ball-to-target performance. As noted above, the most meaningful measure to the golfer is the distance from the ball to the target after the initial putt. The closer to the target that the ball rolls, the greater the probability that it will fall in the hole or of the golfer making the next putt (Diaz, 1989; Gelman & Nolan, 2002). The ball-to-target analyses produced the most directly applicable results related to the mental representation mediation hypotheses. In order to support the hypotheses, the ball-to-target results were predicted to show significant skill differences and relational comparisons between occluded and visual conditions. Both experts and novices showed acceptable levels of accuracy in the occluded and visual conditions and experts were generally superior to novices in both conditions indicating stronger representational mediation. In the single target tasks, the objective of establishing acceptable putting ability from the novice participants was realized. In the occluded condition, the novice ball-to-target mean results were within 6 feet of the target and their absolute directional error from the target was approximately two feet. From a distance of 23 feet, this result is well within normal accuracy for both skill levels. Professionals make over 50% of their "comeback" putts

from this distance (Diaz, 1989). The experts averaged approximately 3.6 feet from the target, very close to the 3 foot radius that many golfers try to be within on lag putts – or to leave putts with a high “makeability” percentage (Woods, w/McDaniel, 1997).

In comparison with their visual performance, both skill groups averaged approximately 2 feet closer to the target in the visual condition. This would put novices close to the desired 3 foot radius from the target and experts within the “tap in” range of two feet, the 93% make rate by professionals (Diaz, 1989). Directionally, both skills averaged about a foot or less from the target in the visual condition.

These results from the single target putting situation firmly establish acceptable putting skill from experts and novices in the occluded condition, supporting the hypothesis of representational mediation in important putting essentials such as analysis of the putting situation, predicting the ball path, establishing an accurate aim line/point, proper alignment and heuristically representing (“feeling”) the critical stroke force. If mental representations are mediators of performance, superior accomplishment is an indication of superior mental representation. Reliable expert superiority in both conditions thus indicated the experts possessed the more refined representations. The single target task results satisfied both major hypotheses.

In the complex putting situation, the ball-to-target results were not expected to reflect the same level of accuracy as in the single target tasks. The putts were “multiple breakers or an exaggerated single break and were quite difficult even with visual access (no professional golfer would want to have to make one of the putts to win a tournament). The additional requirements of relocating the target focus from the original read required visualization of the target 18 or more feet away and no opportunity to read the specific situation added additional constraints to the occluded tasks.

As in the single task putting situation, both experts and novices in the occluded complex condition were, on average, relatively on line and within makeable putt distance from the targets. As expected, the 26-28 foot Targets (1 and 2) showed more variation than the 18-20 foot shorter putts (Targets 3 and 4). The mean ball-to-target measures were between 6 and 10 feet for long targets and 4-6 feet for the shorter targets. With the constraints of occlusion, mental target relocation, regeneration of a new ball path prediction, realignment and the ball rolling over “unread” topography, the results were

quite good for both skill categories. The mean difference of only about 2.5 feet between their occluded and visual long putt performance and 1-2 feet on the short putts is strong evidence of effective mental mediation by the golfers in analyzing, planning and executing putts without the benefit of visual access.

Direction & distance (x,y coordinates). A putt's parameters include both distance and direction. It was initially predicted that experts would be significantly closer to the appropriate x- or y-axis in both direction and distance, but that the largest difference would be registered in the distance parameter. Contrary to this hypothesis, there was a lack of reliable findings in relation to the separate direction and distance coordinates. This posed an interesting conundrum.

Each putt incorporated either positive and/or negative coordinates depending on the quadrant location, and therefore it is possible to obtain a mean of zero (i.e. on target) without ever coming close to the target. For instance, a putt 10 feet past the target and one that is 10 feet short of the target would have a mean closer to the target than two putts that were both a foot past the target.

Each of the four complex targets was verbally specified as a set of coordinates based on the original target that was "read" by the participants (e.g. three feet right and three feet short). A grid was established for each target allowing for positive and negative notation of the individual putt results (Figure 2).

Since putts are a combination of the direction in which the ball is stroked and the force (distance) with which it is impelled, these measures were examined for expert and novice differences. Although it was shown that experts were superior in direction in the occluded condition, its value in understanding accuracy when there are positive and negative measures is not valid. These measures are useful, however, for establishing coordinate notation in relation to other locations on the green, but they are less useful for establishing putting accuracy in relation to the targets. For example, comparing the x_i, y_i coordinates in the canonical correlation analyses.

Absolute measure coordinates ($|x|, |y|$). The results of the absolute x and y distances from the target were more compelling and relevant to the golfing objective. In the single target situation, experts exhibited significantly better direction accuracy, as they did in the quadrant based x results. This is an indication that the results were mostly

on the positive side of the y-axis. The nearly significant expert accuracy advantage (1.5 feet) in the distance measure was also suggestive of a higher level of distance skill.

In the complex putting situations, there was a significant skill difference in distance (except for Target 3 in the occluded condition which approached significance) at each target in both the occluded and visual conditions. There were no skill differences in the directional measures in the occluded condition. However, the average absolute lateral distance ($|x|$) from the occluded complex targets averaged between 3 and 4 feet on the long putts and 2 to 3 feet to the shorter targets. This is impressive based on the difficulty of the putts, the mental relocation of the target and the imprecise representation of the topographic eccentricities. There was only a small improvement on the visual putts (approximately a foot for each target). This level of accuracy shows strong support for representational mediation.

The absolute distance results point to different aspects of golf putting skill. Most golfers are able to envision a reasonably accurate putting line to a visible target and, based on these results, to the target they mentally represent when visual access to the putting situation is occluded. Since the participants' target foci (x_{ij}, y_{ij}) were shown to be unsystematically scattered around the directed target's quadrant, a lack of skill group direction differences was inevitable.

The most significant difference between experts and less skilled golfers is their ability to control putt distance since it is the parameter of greatest variance. The fact that no two putting situations are identical insures complexity in the analysis, planning and execution of each putt. In addition, no surface condition is the same for any putt. The differences in putting uphill or downhill, the type and cut of the grass on the green, moisture or lack of it and influential winds provide an incalculable variety of possibilities from which to analyze and select the necessary force to apply to the ball. Not allowing for any of the above conditions will affect the ball's speed and cause putts to be longer or shorter than expected. World class golfers have participated in many years of deliberate practice, sharpening their knowledge of the effects of many kinds of green surface and environments. In addition, practice and experience have allowed them to develop refined heuristic representations that are effective when adjustments are made from a known coordinate (i.e. the original target). For example, Tiger Woods level of skill and

representational refinement is a product of a highly motivated and encouraged individual who's been practicing regularly since he was 2 years old (Woods, with McDaniel, 1997).

Occluded target focus. As explained in the Results section, the mean of the participants' occluded putts to each target (x_{ij}, y_{ij}) is posited to be their target focus for that target (see Figures 4 & 7). It was originally conjectured that experts would be superior in visualizing the verbally described complex targets because they generally evaluate a larger green area in reading the green and predicting ball paths. The results did not offer reliable support for the ability to precisely locate the verbally described targets, but they did indicate representational mediation in envisioning the relative target positions for both skill groups.

In the single target putting situations there was no target relocation and the participants could mediate their putts based on the specific representation gleaned from their green analyses. In the complex situation, individual mean (x_{ij}, y_{ij}) distance to each target indicates the golfers' abilities to relocate the target in reference to the original target based on the verbally described coordinate set. The golfer's means ranged from 0.4 to 10 feet from the target position in the single target situation and 1 to 15 feet on the long complex targets and 1 to 9 feet on the short complex targets.

Even with the wide variance in target focus, both experts and novices were able to limit their mean x_{ij}, y_{ij} positions to within 3.7 feet of the single occluded target and 6.2 feet and 3.8 feet of the long and short complex occluded targets respectively. These results show that the golfers were able to create and maintain representations that mediated a mean variance from the target of six feet on the longest, multi-breaking putts from a distance of 26-28 feet. Professionals will convert over 50% of these 3 to 6 foot "comeback" putts (Diaz, 1989). Novices would miss a larger percentage of these length putts, however, they are prone to more three and over putt greens when they have visual access (this study's novices averaged over 9 three putt greens per 18 holes).

These results are very supportive of representational mediation in golf putting considering that the participants in the occluded complex situations were asked to perform the unfamiliar task of mentally relocating the target and then visualizing and forming a new representation of the new putting situation with vague and imprecise information.

Occluded and visual condition comparisons. The most compelling results from the between condition measures resulted in a reassessment of target relocation capabilities. The hypothesis that experts' occluded results would be closer to their visual results was based on the assumption their golf skills would allow them to accurately relocate the targets based on the investigator's verbally communicated coordinates. The results of the ball-to-target, and x_{ij}, y_{ij} coordinate-to-target condition comparisons indicated significant differences between conditions on several targets and thus did not support this assumption. On the other hand, the putt-to- x_{ij}, y_{ij} coordinate results between conditions show equality between conditions for both experts and novices.

Finally, the variation in distance putting was not unexpected since golfers generally use their visual sense to "communicate" with their mental representations of putting in order to develop "feel" for the putt. To have less than a two foot difference between the occluded and visual putts for both experts and novices (absolute measure) was quite remarkable considering the difficulty of the putting situations and the absence of the normal visual cues. The occluded and visual task results indicate well established internal representations of golf putting in general and the experts' superiority in the absolute measures indicates higher representational refinement.

Difference in Expert and Novice Performance

Expert performance research embodies the comparison of expert and lesser skilled performers in representative tasks in a domain in order to identify the main contributors that differentiate the mediators generating high performance from those mediating lesser or ordinary performance. This study hypothesized not only that mental representations mediate performance in golf putting, but also that the more refined and developed one's mental representation, the higher the skill level (Ericsson, 2006; Ericsson & Lehmann, 1996). As shown above, support for representational mediation in golf putting was indicated by acceptable putting results in occluded putting tasks. Therefore, it is reasonable to conclude that when comparing low handicap golfers to average or novice golfers any separation in their performance can be attributed to their more refined and effective representations. The putting tasks reported above will be discussed as they pertain to differences in levels of performance.

Ball-to-target performance. In the single target putting situation, this study's expert golfers demonstrated their superiority by putting, on average, significantly closer to the target (ball-to-target distance) under both occluded and visual conditions.

In the complex putting situations, the ball-to-target distance analyses show overall expert superiority in both occluded and visual conditions, although two targets (Target 2 & Target 3) only approached significant skill differences. On both of these targets, experts still averaged closer to the target by at least a foot, increasing the chances of making the "comeback" putt. The lack of an interaction indicates that the results were not predicated on condition, however, the length of the target did show significant differences as would be expected.

In the Results section it was explained that these targets were on the left side of the original ball-target line and the unique topography along the ball paths may have promoted wider variance than was expected on these putting situations. On both targets, both skill levels tended to be short, indicating erring on the conservative side since the down slope past the target was more extreme and would cause the ball to finish farther from the target than if the ball was short. Generally, novices tend to be short on most putts and miss on the low (or "amateur") side. Experts will try to aim past the hole by a foot or two to insure that if the ball is on line, it will drop. By being conservative, experts were more likely to match the novices' natural timidity. Of interest, however, is the reliable difference in distance on Target 2 and near significant Target 3 distance difference.

Throughout this discussion, it is important to keep in mind that the golfer's major objective is to putt close to the target and that the ball-target results represent their level of expertise in golf putting, but it should also be noted that the putting situations are quite difficult. Diaz, 1989, showed that tour professionals average making only 16% of their 20-foot putts on a mostly level, green surface. With the degree of difficulty of this study's putts, visual condition putts would be expected to show a much lower percentage and the chances of hitting an occluded target at this distance are remote (although it did happen).

In the occluded conditions, all participants showed that they were able to use their mental representations of the putting situations as the mediator of their putting results to some level of competence, since visual access to the putting situations and targets were

not available to them. The experts' mostly reliable superior results suggest (but not beyond doubt) that their representations are more complete and more refined than the novices'. In addition, the application of their representational based analysis may be focused on different priorities. Their superiority extended to the visual condition, where, though they were able to visualize the putting situation they still had to mentally represent the ball path in order to establish their aim points and stroke the ball in the correct direction and for the correct distance. These results provide evidence of the skilled golfers' representational advantage over the novice golfers.

Direction and distance coordinates. As discussed previously, the coordinate points establishing the relative position of the ball coordinates to the targets. A canonical correlation comparing the ball and target coordinates indicated a strong relationship for both experts and novices. However, there was no skill group difference in the occluded condition leaving a question about expert representational superiority. This will be discussed in detail in the *Comparative Skill Group Section*. The absolute values of the x and y distances from the axes are more informative regarding putting skill.

The single target absolute value results in both conditions for both direction and distance showed expert superiority, except the occluded distance difference which was near significance ($p = .054$). Also in the occluded complex situation tasks, experts were significantly closer in distance to the target (except Target 3 which again approached significance at $p = .073$). In this condition, however, there were no skill group differences in the direction coordinate.

Golfers most often take their cue on distance and the necessary stroke force from their heuristically represented "feel" when addressing the ball and visually estimating the target distance. Initially this was done on the original read. When the screen was set in place for the occluded tasks, the participants had to align themselves with their visualized target and execute the putt. Since the golfers had only a vague representational concept of how to mentally calculate standard measures from 20 or so feet, their mental relocations of the target were varied and mostly inaccurate. Thus, their aim directions resulted in wide putt variations within the participants. On the other hand, force applied to the ball is a heuristically represented concept acquired from practice and experience. Thus, the amount of deliberate practice, establishes more refined heuristic gradations incorporated

into a golfer's putting mental representation. As such, the more highly practiced experts were able to apply finer gradations of force on a "greater than/less than" basis related to the original target.

The generally superior absolute distance results of the experts does support the hypothesis that expert performers have acquired more highly refined golf putting representations allowing for finer gradients of analysis, planning and execution of their putts. This is particularly true of the representational "guidance" to the motor system, since the basic physical aspect of distance is the force with which the ball is stroked. The difficulty in accurately representing and predicting the ball path in the complex situations was largely a consequence of target relocation and the lack of specific knowledge about the topography to the relocated target.

Occluded target focus. These results are very supportive of representational mediation in golf putting considering that the participants in the occluded complex situations were asked to perform the unfamiliar task of mentally relocating the target and then visualizing and forming a new representation of the new putting situation with vague and imprecise information. The lack of group differences (discussed in the next section) indicated less definitive and refined mental representations of the current putting situation and therefore less effective mediation of performance. This is not unlike chess masters trying to represent and recall chess pieces from randomly situated chessboard positions (Chase & Simon, 1973).

The non-reliable skill group differences in both direction and distance measures from the target axes led to an investigation of the accuracy of the participants' representations of the target. Since the participants' mean coordinate points are the best observable evidence of their visualized target focal point, it was predicted that experts' mean target focus would be closer to the actual target than the novice means. The results of the comparisons, however, showed no significant skill group differences, although the experts did average 1.4 feet closer to the target showing their inclination toward more accuracy. Although the skill difference in the occluded condition wasn't significant, the additional accuracy of the experts would give them a 10% greater chance of making the "comeback" putt if they were both tour players (Diaz, 1989).

Two possible explanations may account for these results. First, the hypothesis of superior expert representational mediation could be invalid, but the fact that it is not necessary to relocate targets in golf putting would suggest that golfer's have no need to develop this skill. Second, since there is no evidence of acquisition of target relocation skills (particularly in an occluded condition), we can deduce that the participants were not highly skilled in this task. As such, it is not reasonable to expect them to have mastered this ability.

Explanations for the equivocal results may be found in two basic tenets of deliberate practice, hours of practice and feedback (Ericsson et al., 1993). First, the participants' lack of deliberate practice in occluded performance necessitated a coordinate estimation based on an unsophisticated mental representation. In order to avoid any participant preplanning during the green reading task, they were not aware of the task they would perform. They expected that they were to putt under occluded conditions based on the non-complex tasks and that they would be putting to the target that they were visually analyzing. Their analyses were concerned with visualizing that target, selecting an aim point and, particularly for the experts, establishing their distance evaluation. When they were surprised with the additional requirement to relocate the target and putt to the new target under occluded conditions, results indicated that accurate relocation was not within their putting skill set. The golfers' performance indicated that neither skill level is adept at mental target relocation, particularly on longer putts of 20-or-more feet. Mental distortion of each participant's concept of a foot applied to a longitudinal or latitudinal position 20 feet or more away, might challenge the most expert engineer (Baird & Burkhart, 2000; Gibson & Bergman, 1954). It is therefore understandable that neither experts nor novices as a group were very consistent in their visualizations of the verbally described target coordinates. Thus it follows, that when they aimed at a location away from the designated target, the resulting putts would not approximate the target location as accurately as putts to their target focus.

Second, the golfers were given no feedback, a key factor in improving through the deliberate practice concept. They had to continue to key on their original visualized targets and try to maintain consistency with their putts to each target. As a consequence, their accuracy in respect to the target was dependent upon the extent to which they were

accurate on the originally visualized target. During the occluded tasks, many of the participants said that they gradually lost their focus on the original target causing variation in their focus for the relocated target positions. The lack of accurate and consistent focus on the designated target points indicated that putts to their presumed target focus might be more informative.

Interestingly, although there were no skill differences in direction due to erroneously relocated targets and vague topographical representations, experts were able to establish reliable superiority in the distance parameter. As noted before, it is posited that experts have more finely incremented progressions of force incorporated in their heuristically based distance representations mediating their performance.

Variability of accuracy in putt- to- x_{ij}, y_{ij} point. If the golfers were not, in fact, visualizing the described target, it was necessary to ascertain their accuracy in putting to the target of their mental focus (x_{ij}, y_{ij}).

The results of each golfer's putt distance from his/her x_{ij}, y_{ij} coordinates showed that experts' putts were closer than novices to their means by almost a foot or better, although the left side putts (Targets 2 & 3) individually only approached significance, thus mirroring the ball-target results. The experts did, however, average about a foot closer to each target. As explained earlier, the characteristics of these targets, with the experts exhibiting caution against going too far past the targets, may be responsible for the absence of significant effects. The experts' more accurate putting to their target focus is indicative of their ability to putt effectively to their envisioned target in the occluded condition, and the actual targets in the visual condition. This is a further indication of the mediation effects of the golfers' mental representations in putting and their mediation effects in analysis and execution of putts. Wherever the target is represented, it is established as the goal and the golfers' are able to analyze the situation and putt to it. If the representation is inaccurate, the putt will be inaccurate to the same degree as the golfers' skill in analyzing, planning and executing putts

The study analyses also showed that the consistency of the participants' average putt distance to their independent means (assumed target focus) were not significantly different between the occluded and visual conditions, except for novices on Target 2. This indicates that the golfers tended to be equally consistent in putting to their target

focus in either the occluded or visual condition. Experts still tended to be more consistent (less distant) around their target focus than were the novices, but the ball-to- x_{ij}, y_{ij} equality shows that both experts and novices were effectively using their mental representations for performance mediation in the occluded condition as well as they use their visual perceptive abilities in the visual condition. The fact that the experts were superior to novices in both ball-to-target results and in the putt distance to the individual means argues in favor of expert mental representations being more refined and providing a superior basis for analyzing, planning and executing putts.

Future research, combining this research with the aim point research in Hill (1999), will be able to more closely pinpoint the represented target locations of expert and novice golfers when the putting situation is occluded.

Perhaps the most influential constraint in the complex situations was the requirement for the participants to relocate the target and mentally construct the altered ball path over unread topography, resulting in significant variations in target focus and aim direction. There was a significant difference between the individual means (x_{ij}, y_{ij}) and the alternate target coordinate point specified by the investigator. Since the target focus was not necessarily the same for all participants, nor in proportion to skill group, the skill comparisons for individual centroid distance to the alternate targets were not indicative of skilled performance. However, when it was recognized that target relocation was not within the skill set of the experts, putts to the golfer's individual means (ball-to-centroid) revealed that experts were generally superior to novices when putting to their target focus.

A final compelling observation revealed by the between condition analyses was the basic equality between expert occluded performance and novice visual performance. This was also true in the single target putting tasks. All of the novices are considered average to somewhat above average golfers, some with above average putting skills. The fact that the experts are able to perform at an average-plus level under unfamiliar occluded conditions indicates the advantage of a stronger representational basis for skilled putting and supports the hypothesis that experts have acquired more highly refined mental representations attributable to many hours of deliberate practice.

In summary, the variability analyses strongly indicated expert superiority in putting to their targets of focus, although the target focus was not necessarily the directed target position. The assumption that the x_{ij}, y_{ij} means were the golfers' target foci, other factors also may have affected the final position of participants' putts (e.g. strong wind, unfamiliarity with occluded putting, etc.).

Occluded and visual condition comparisons. The hypothesis that experts' occluded results would be closer to their visual results was based on the assumption their golf skills would allow them to accurately relocate the targets based on the investigator's verbally communicated coordinates. The results of the ball-to-target, and x_{ij}, y_{ij} coordinate-to-target condition comparisons indicated significant differences between conditions on several targets and thus did not support this assumption. On the other hand, the putt-to- x_{ij}, y_{ij} coordinate results between conditions show equality between conditions for both experts and novices.

A comparison of the occluded and visual condition results, showed the individual centroid differences (target focus) for both skill levels and in both the single target and complex putting situations were predominantly superior in the visual condition. It might be therefore argued that the golfers had little representational clarity from their original read and thus were mediating their putts with poor representations or a perceptual vacuum. On the other hand, the golfers, both expert and novice, are not required to mentally relocate targets and thus have never mastered the capability. The single target task with no relocation showed that novices improved their putt direction significantly in the visual condition, while the experts were essentially equal (< 3" difference). Although the experts did improve significantly in the absolute direction measure, the improvement was only 5" while the novice improvement was over a foot. This leads to two conclusions. First, the golfers were able to represent the putting situation in the occluded condition after an initial visual analysis, and second, most of the overall variance comes from the distance parameter. Thus, it is argued that the target focus (x_{ij}, y_{ij}) in the complex occluded condition was not a generally acquired skill in golf and therefore the resulting putt means varied differentially between golfers. In addition, golfers were unable to closely analyze the topographical conditions and were required to visualize the ball path based on a much less precise representation of the relocated putting situation.

Experience and deliberate practice indicators. Self report questions about each golfer's experience and practice histories were analyzed regarding their correlation to performance and skill group differences. Since deliberate practice and related experience are the cornerstone of Ericsson and colleagues expert performance models, their predictive capability in golf would reinforce the concept.

The results showed strong, significant correlations between ball-to-target putting performance and the predictors including their first time playing and number of days/ hours practicing and also their performance history records such as number of one- and three-putt greens and handicaps. Experts were significantly different from novices in all of these categories.

Although these analyses are based on self-report information, the extent of the differences argues that the results are realistic. It is recognized that the results based on this sample are not conclusive, however, the results do define reasonable differences and support for higher level skill acquisition through the deliberate practice model.

Comparative Skill Group Results Indicating Representational Refinement

In the initial section the hypothesis that Ericsson & colleagues theory of mental representation mediation in performance was supported in the domain of golf putting. A canonical correlation indicated that both experts and novices were able to guide their putts to the appropriate target quadrant in the occluded complex tasks. In addition, the ball-to-target measures, showed that both experts and novices were able, on average, to putt within approximately six feet of the target which leaves comeback putts that are made around 50% of the time by top golfers. Since the putting situations were screened from the golfers' view, the ability to mentally establish a reasonably accurate ball path and putt within a reasonable distance of the target indicates representational guidance in analysis and planning of the putts.

Consideration must be given to the golfers' practiced putting stroke, so that the ball path and force estimations can be executed accurately. However, the mental analysis and planning under occluded conditions give credence to the concept of representational mediation in putting.

The second hypothesis stems from the *a priori* projection suggesting that higher level performance is a result of more effective and refined mental representations. Thus,

the experts, as the higher level golfers, were expected to perform at a higher level as a result of their more effective operative bases from which to analyze and plan each putt. In fact, superior performance by experts was indicated in most occluded tasks. Also, where no significant skill difference was noted, experts were closer to the target on average, and generally at near significant levels (i. e. $p < .10$). These results indicate higher level expert performance on the occluded tasks, however, they are not absolutely attributable to the mediation of the golfers' domain mental representations. First, the higher skilled players had a history of many more hours spent on the practice green and playing, honing their putting stroke. Therefore, some of the differences may be the results of better technique and execution. Secondly, in the complex situations the ability to mentally relocate targets and to expand the green area from the original read to encompass the new target locations is not a skill normally faced by golfers and thus would have affected their ability to visualize accurate ball paths and stroke force predictions.

A golfer's mental representations on putting embody both episodic and semantic knowledge in both strategic and motor functions gained from experience and deliberate practice in the domain. The top players have generally mastered all knowledge of the greens and other environmental effects on a rolling golf ball as well as physical practice in developing a consistent and repeatable putting stroke that can be implemented by the golfer under often stressful conditions. Their mental representations are compilations of this experience

Putting differences between golfers comes not only from the depth and refinement of their representations but more importantly from how they use their representation and the current information to determine the projected ball path when hit with the proper force. The previously discussed canonical correlation comparing the post-putt position coordinates with the four target coordinates in the occluded complex situation revealed high correlations by both experts and novices. However, the comparative analysis of each golfer's correlation showed an interaction between skill level and condition indicating no reliable skill difference in the occluded condition but a significant expert superiority in the visual condition.

A direct interpretation of these results suggests that highly skilled putting requires continual visual access to the putting situation more supportive of a perception-action

framework than a representational one. However, the circumstances of the tasks and different approaches by the golfers offer other possibilities. For example, the requirement for participants to relocate the target from the originally analyzed target position base on the investigators verbal measurement directions required a mental exercise unfamiliar to the golfers. Neither skill group had developed strong representations of linear measures projected 20 feet away. Thus, their envisioned targets were unsystematically scattered based on each individual's concept of increments (in feet) and their representation of the original target location. In addition, they were not given an opportunity to analyze the putting situation for their envisioned target location, thus their representation of the topography would be vague. Both of these conditions deny the golfers a chance to accurately determine a ball path to the specified targets and prevented the experts from taking advantage of higher level representations in establishing the direction in which to stroke the ball.

As a comparison to the complex constraints, the single target task allowed for reading the exact putting situation with no target relocation. The ball-to-target results showed expert superiority in direction and generally in distance. In the occluded condition distance measure, experts were 46cm (1.5 feet) closer to the target, which was not quite reliable. It is, however, reasonable to deduce that the opportunity to read the putt allows the experts to utilize their updated and more refined representations to mediate their performance at a reliably higher level.

The single target putting situation was more straightforward and without the multiple breaks, however, it affects both skill groups. The expert superiority in the direction parameter is indicative of the advantage they have when they have a clear representational concept of the topography and target location. Comparisons of the single target putt-to-centroid to the complex targets revealed greater consistency by both skills (excepting Target 3) on the single target putts. The opportunity to represent a known target is an advantage when establishing a putting direction.

Distance, on the other hand, is based on heuristic representations of the club speed necessary to apply the necessary force to reach the target. The distance estimation to the original target can be mentally modified by highly practiced golfers by adding or subtracting slightly more or less force without the requirement for precise measurement.

Experts' more refined representations of distance (force) gradations ("feel") would be expected to produce more accurate distance putting. In addition, expert golfers and teaching professionals stress distance analysis as the highest priority, whereas most novices will be concerned with direction and rely on more basic "feel" representations to stroke the ball causing more distance variation.

The results of individual direction and distance correlations and absolute distance measures support this interpretation. A comparison of expert and novice direction correlations indicated no skill differences, though there was a difference in occluded and visual putting. This indicates that the task constraints on green knowledge of the current putting situation diminished any representational analysis of the ball path and thus experts had little or no advantage over novices. Distance, on the other hand, could be estimated based on the original read and heuristic adjustments where experts had refined their representations through deliberate practice. The comparison of skill group distance correlation differences showed superior expert results in both conditions. Also, t-test differences for occluded putting showed no direction skill differences but distance differences were significant. Experts were superior to novices in both direction and distance in the occluded condition where both target location and topographical information was available. This not only supports expert superiority in distance representation, but also shows a different approach to putts that prioritizes distance over direction. Future studies isolating both distance and direction parameters can provide important follow-on information to this study, further defining representational issues that may mediate putting superiority.

The correlation results were reinforced by the absolute direction and distance measures that showed the same pattern of results. Skill differences in direction were not significant in the occluded condition but experts were superior in the visual condition. In the distance results, reliable expert superiority was evidenced in both conditions.

The occlusion and task constraints effects caused by target relocation are a thread running through all the results in this study. The ball-to-target and putt-to- x_{ij}, y_{ij} reflect not only greater expert consistency but also superior distance control by experts. This is shown by the larger proportion of the hypotenuse (ball-to-target distance) attributable to distance in all occluded cases. The almost equal expert and novice mean directional

measures in the occluded condition (largest difference: 17 cm or 7 inches on Target 1) indicates the inability of experts to establish superiority. As with chess experts, they have difficulty recalling chess positions when they are not relevant to their representation of chess play. The golfers were not able to use superior representations in putting skill without being able to effectively incorporate the current situation information. Expert focus on direction and superior heuristic representations of force-to-distance calculus allowed them to continue superior performance using “greater than/less than” analyses.

The lack of clear target and topographical information also was directly attributable to the non-reliable skill differences in the x_{ij}, y_{ij} -to-target distances. Since the x_{ij}, y_{ij} locations were all in the proper quadrants, the differences can be attributed to lateral judgments and in all but the Target 3 situation, the sharp slope of the green to the right.

Finally, the methodology of the study entailed resetting and reassessing for each putt in the complex condition. Each putt presented a situation that had to be reassessed for both direction and distance. The fact that each putt was designated to the left or right of the original target, the golfers had some guidance to the direction parameter. However, imprecise estimates of target locations and complex topographical conditions made representation of the ball path to the directed target highly unreliable. On the other hand, distance had to be determined based on whether it was longer or shorter than the original target, which was 23 feet away. The ability of the experts to show reliable superiority in this putting parameter shows that they had fixed the original target distance in their representation from which they could add or subtract distance to meet the requirements of each putt.

In sum, the demonstrated ability to mentally analyze and adjust each putt to meet the demands of a different putting situation and consistently come closer to the target than novice golfers, shows more effective mental representations when updated with the necessary information from the current situation. When the information is not available, the putt analysis becomes only slightly more than educated guesswork.

Mental Representation Mediation Summary

In summary, it was hypothesized that performance is mediated by one’s mental representations of domain tasks. The occluded condition tasks produced mean results for both skill levels that were within what would be expected of the golfers playing

accomplishments. Though some golfers were outside one standard deviation from the skill group mean on some tasks, the overall means were within “comeback” putt distances from which professional golfers would sink the putt over 50% of the time (Gelman & Nolan, 2002). Amateurs would, of course, be expected to have a lesser success rate, however, the average putts are certainly makeable by both experts and amateurs with reasonable experience.

The occluded condition, as previously established, required that the golfers rely on their mental representations of the putting situations to analyze, plan and execute their putts. The ability of the golfers to execute their putts with acceptable accuracy based on their mental representations gives strong support to the representational mediation hypothesis.

In the single target putting situation tasks, cross condition performance largely indicated superior performance in the visual condition. As the first set of tasks, unfamiliarity may well have played a part in the results, however, mean absolute direction variance from the targets was 2 feet for novices and only a foot for experts. Though each improved in the visual condition, they had the advantages of feedback and experience with a familiar putting situation, which was not available in the occluded condition. Improved distance accuracy in the visual condition is also conjectured to have resulted, in large part, from feedback and experience.

Cross condition performance was mixed in the complex situations, with visual ball-to-target superiority for all except Target 1 and novice Target 2 performance. The separate direction and distance coordinate differences were also mixed, with Target 1 more likely to show no condition differences and the left side targets (2 and 3) exhibiting superior visual performance. Therefore, for the measures most relevant to golfers, visual access to the putting situation provides an advantage for golfers, though contrary to expectations, somewhat less so for the novice golfers.

In retrospect, the major cause of the condition differences is posited to be the lack of skill in mentally measuring units of distance at a distance of 23 feet based on verbally communicated coordinates. This aptitude is not normally part of the skill set of expert golfers and even less so for novices. In that the golfers were not accurately representing the target location, the resulting putting performance would not be expected to equal the

performance when the golfers can precisely pinpoint the target. The interesting point of these results is that both experts and novices did perform well enough in the occluded condition to average makeable “comeback” putt differences. Some reasons for this may be the participants’ lack of familiarity with occluded putting and the lack of feedback.

The results of the occluded tasks that require representational mediation to perform, have provided strong evidence for the Ericsson, et al. (1993) model establishing mental representations as the primary mediator of performance and the basis for analysis, planning, decision-making and execution of behavior. Other theoretical models of performance that exclude representational mediation would not explain the performance of the golfers on the occluded tasks.

The complex putting situations supported expert superiority in basic golf putting (ball-to-target distance) in the visual condition. In the occluded condition, experts were closer to the target on all targets, but only approached reliable superiority on two targets. These were the left side targets which were somewhat unique putting situations. Target 2 influenced the expert golfers to be more conservative in their putts while novices are generally less aggressive, resulting in equally short putts from both skills. Target 3 was a single break putting situation which may not have required the highly refined analyses of the other situations (Hill, 1999). Overall, experts did exhibit a higher level of performance on the complex tasks. In addition, when performance was evaluated based on presumed target focus, the same pattern occurred, indicating that both experts and novices were not highly skilled at relocating the target, but experts again showed superiority when putting to their intended targets.

A portion of the skill group differences are attributable to the greater consistency of the experts’ well-practiced putting stroke. However, the greatest contributor to expert superiority is distance control. Their highly refined heuristic representation of the force and distance confluence allowed them to putt from target-to-target in an unsystematic rotation with reliably superior results while visual access to each target was occluded. The performance results, therefore, can be ascribed to representational mediation rather than basic consistency.

In the comparisons between conditions, both experts and novices were superior in the visual condition although it was predicted that only novices would show a difference.

This would appear to show that experts' mental representations were not refined to the point where they could imitate their normal visual performance. However, when the differences between conditions were based on the ball-to- x_{ij}, y_{ij} distance, no significant advantages were found for condition, although experts' outperformed novices in both conditions.

An important final consideration in these analyses is the limited number of available low handicap golfers allowing for only a relatively small number of participants. Since many target analysis approached significance (i.e. $p > .06$, $p > .07$, etc.), it is very possible that the number of participant pairs were not able to generate sufficient power to adequately define effects (Type II error).

Overall, these analyses support the hypotheses that mental representations mediate performance and that the more comprehensive one's representations, the higher the performance level.

CONCLUSION

The purpose of this study was to understand how the concept of mental representation mediation of expert performance may apply to the domain of golf putting. This domain provides a rich setting for applying the cognitive components of expert performance including problem analysis, planning, decision-making and action application. The deliberate pace of putting allows for examination of each of these components without breaking the stream of action.

Reading the green encompasses analysis and evaluation of the constraints and environmental influences on a rolling golf ball, estimating the path the ball will take to the target if stroked in the envisioned direction with the necessary force and then planning the stroke by selecting an aim point/line and a heuristic estimate of applied force. The evolved representation of the putting situation then guides the golfer's motor execution of the putting stroke.

Based on expert performance theory, it was conjectured that expert golfers, through many years and hours of deliberate practice in reading greens and stroking putts, have developed highly refined mental representations of putting situations, environmental effects on a rolling golf ball and a reliable and effective putting stroke (Ericsson, 2006, 2003; Ericsson et al., 1993; Ericsson & Smith, 1991). Golf putts are never quite the same due to different positions on the greens and continual environmental changes. When faced with new putting situations, golfers must evaluate and incorporate the new putting situation into their golf putting representation and based on it, analyze and plan the necessary direction and stroke force for executing the putting action.

In general, experts were able to outperform novices in all of the tasks. Although some analyses did not reach a level of significance, expert putts, on average, were closer to the target than novice putts. Those that didn't approached a significant level. From these results, it can be said that there is impressive evidence that a golfer's domain representations are a strong mediator of putting in golf. It should be noted, however, that experts have many years of deliberate practice with the intention of improving their

putting. As such they have developed a highly consistent putting stroke which, under most circumstances, will produce a high level of consistency that the average novice will not attain. This is a major advantage for the experts, regardless of how well the novices may mentally represent the putting situation.

In some cases, the consistency advantage, and not a representational advantage, could be the major difference in task differences. However, in the complex situation, an effort was made to isolate the representational contribution by unsystematically rotating the putts among the four targets so that each putt had to be realigned and distance be recalibrated. Of course, there will always be some advantage to a consistent stroke, but having to reanalyze each putt in the occluded condition demands representational mediation.

The overriding theme through all the analyses is that although a golfer's representation of golf putting is reliant on current situation information, once a base distance has been established, changes in distance requirements are effectively represented by experts whereas direction is reliant on examination and analysis of the specific putting situation. If the target is moved within a few feet of a known target situation while the situation is visually occluded, neither experts nor novices were able to effectively mentally relocate the target and establish an accurate new ball path to the directed alternate target. In the occluded complex putting situations, there were no skill differences in absolute direction measures. On the other hand, three of the four targets showed expert superiority while Target 3, the shortest and most basic putting situation, approached a significant difference. Conversely, in the single known target situation, the participants were able to read the putt and then under occluded conditions, execute putts to the target. Experts then exhibited superiority in direction and near significant superiority in distance.

These results indicate that representations cannot be effective in mediating superior performance without accurate information pertinent to the current domain situation. However, well practiced skills, such as distance putting are heuristically represented, thus they can be effective mediators in analyses of the putting situation using "greater than/less than" indicators. The superiority of the visual condition versus the occluded condition does indicate that the insight derived from visual access is an

important factor. This may be due to habitual reinforcement of the golfers' representations, consistency of situation information or just non-familiarity with occluded putting. Additional, studies in both distance and direction parameters will be helpful in extracting mediating representational components that provide additional expert advantages.

The hypothesis that experts would be able to effectively relocate the targets and recall accurate topographical information from their original read, while novices would not, was not valid. The unsystematic variations in the golfers' mean coordinates showed high within group inconsistencies. Based on the results, golfers need precise target location information and a concept of the topography of the ball track to adequately determine an aiming direction (aim point/line). It is, of course, evident that if one is aiming in the wrong direction, the ball will not come near the target. Both location and topography are necessary to analyze and plan for the putt. Future studies should investigate the differences between relocating and putting to a target while vision is occluded and being able to read the putting situation before putting in the occluded condition.

In all of the tasks performed, experts were able to utilize their more refined representations in respect to distance to create differentiation with novices. Distance is normally the larger component of the ball-to-target distance (hypotenuse of distance/direction triangle) since most golfers can come closer to the target laterally than longitudinally based on their representations of the ball path. In the complex situation, both skill groups had difficulty in establishing an accurate ball path to the designated target, thus leaving distance as the main determinant of superior performance.

This study is intended as an initial study in the use and mediation of an individual's mental representations when analyzing, planning and performing motor skills. Empirically testing representational mediation to better understand its evolution in the refinement process will allow for methodology to emerge that will enhance deliberate practice techniques and lead to further performance improvements.

Future investigations will attempt to understand how golfers attempt to locate occluded targets and their ability to lock in their representation of the putting situation (or other task situations) over the time it takes to perform the elements of the occluded task.

Another important investigation will compare blind occluded putting with pre-putt green reading prior to occlusion. The distance parameter can be investigated through precise measure differences and through heuristic “greater than/less than” tasks. In addition, studies can be developed to examine distance differences between visual and occluded conditions. As Tiger Woods says, “a great way to improve your feel is to putt you’re your eyes closed. After each putt, try to guess how far the ball rolled. This is the best drill for control I know of” (Woods, 2001, pg. 22). It would be worth exploring this advice from the world’s best golfer.

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BIOGRAPHICAL SKETCH

Leonard A. “Len” Hill was born in the nation’s capital, Washington, D. C. and moved to Long Island, New York with his family when he was ten. After high school he attended the University of Mississippi, receiving a Bachelor of Arts in Mathematics and a commission in the U. S. Army. He spent two years in the Counter Intelligence Corps developing intelligence plans and procedures and managing operational finances. Returning from active duty, Len joined the IBM Corporation in New York City, establishing a career in marketing and marketing management. During his career, he managed the development of several IBM exhibits and managed IBM operations at two World’s Fairs. In addition, he managed nationwide promotions of major new product introductions, managed operations at major company conventions and managed the trade show marketing program for personal computers. During his tenure at IBM, he attended Pace University in New York and earned a Master of Business Administration degree, with distinction.

In 1990, Len accepted IBM’s early retirement offer in order to work on other business ventures. After six years, the desire to continue his education resulted in a fortuitous meeting with Florida State University’s Conradi Eminent Scholar, K. Anders Ericsson, and lead him to pursue a new educational path, cognitive psychology. He became a graduate student with Dr. Ericsson, specializing in the mediation of mental representations in expert performance. He plans to continue research in this field.