12-2014

Investigating the Role of a Reduced-Instruction Approach in Implicit and Explicit Motor Learning Strategies

Kevin Michael Fisher
University of Tennessee - Knoxville, kfisher9@vols.utk.edu

Recommended Citation

Fisher, Kevin Michael, "Investigating the Role of a Reduced-Instruction Approach in Implicit and Explicit Motor Learning Strategies. " PhD diss., University of Tennessee, 2014.
https://trace.tennessee.edu/utk_graddiss/3124

To the Graduate Council:

I am submitting herewith a dissertation written by Kevin Michael Fisher entitled "Investigating the Role of a Reduced-Instruction Approach in Implicit and Explicit Motor Learning Strategies." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Kinesiology and Sport Studies.

Jeffrey T. Fairbrother, Major Professor

We have read this dissertation and recommend its acceptance:

Leslee A. Fisher, Schuyler W. Huck, Joe Whitney

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Investigating the Role of a Reduced-Instruction Approach in Implicit and Explicit Motor Learning Strategies

A Dissertation Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Kevin Michael Fisher

December 2014

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

"The real world doesn't reward perfectionists. It rewards people who get things done."
- Ziad Abdelnour

ACKNOWLEDGEMENTS

As my parents would say in reference to cards or life, one has to "play the hand their dealt." Throughout my life, I have been fortunate enough to receive some good hands. I have two loving parents, a supportive family, and good friends, and I recognize that I would not be where I am today without the presence and influence of all of these people. I have also been fortunate enough to have a wonderful committee that has helped me throughout this process: Dr. Jeff Fairbrother, Dr. Joe Whitney, Dr. Sky Huck, and Dr. Leslee Fisher. Many hours of reading, writing, and discussion have gone into this project, and it would not have been possible without their knowledge and willingness to help. While it is not possible to thank everyone individually, I would like to specifically mention a few people.

Mom, Dad, and Buddy. Thanks for your unconditional love and support. And for Buddy, who has always welcomed me at the door with excitement and love.

Minha Kim. From the first day I met her, Minha has brightened my life and brought me great joy. I will never forget our adventures and all of the love and support that you have demonstrated for me along the way.

Dr. Jeff. I have been extremely fortunate to work with Dr. Fairbrother. He has allowed me to pursue the topics and questions that interest me, and his advice and guidance has been invaluable. I look forward to seeing his surfer shirts at NASPSPA for many years to come.

The Lab Group: Kevin Becker, Ary Alami, Anders Holmberg, and Dave Laughlin. I have had the pleasure of studying alongside a great group of peers while in Knoxville. The countless conversations and jokes along with opportunities to hang out have made this process an enjoyable one, and your help and friendship will not be forgotten.

Friends from South Boston, Greensboro, and Knoxville. Although we are separated by time and distance, I will always value your friendship and cherish the fun times that we have spent together.

The SKLZ Golf Division. The folks at SKLZ were kind enough to supply me with their Vari-Break Putting Green for the purposes of this project, and it has performed beautifully. With a smooth, consistent roll and the ability to create both straight and breaking putts, it is an extremely useful tool for both personal practice and putting research.

ABSTRACT

Traditional explanations of motor learning contend that skills are learned explicitly in a process in which learners accumulate declarative knowledge and progress through distinct stages of learning (e.g., Fitts & Posner, 1967). More recently, implicit approaches to instruction have been used in an attempt to bypass accumulation of explicit knowledge. Such approaches have been shown to facilitate motor learning compared to explicit instruction by enhancing skill retention and transfer under conditions involving distraction, increased pressure, or physical stress (Masters & Poolton, 2012). One method thought to invoke implicit learning involves instructions in the form of an analogy (Liao & Masters, 2001). Researchers have typically compared the effects of a single analogy statement to those of explicit instructions consisting of up to 12 statements (Liao & Masters, 2001). Thus, observed differences between these approaches could be attributed to different attentional loading. The purpose of this study was to compare the effects of analogy instruction on the performance and learning of a motor skill to those of explicit instruction consisting of a single statement (i.e., an equivalent amount of instruction). Participants (n = 48) practiced a 10-foot golf putt under one of four instructional conditions: Six-Rule Traditional Explicit Instruction (TEI), One-Rule Explicit Instruction (OREI), Analogy Instruction (AI), or no instruction (CTRL). Results indicated that the AI and OREI groups made more putts than expected during acquisition while the CTRL group made fewer. During Retention 1 and 2, however, the number of putts made was similar to what was expected, indicating that initial differences in performance of the primary task were eliminated with practice. During Transfer 1 (breaking putt), the TEI group made fewer putts than expected, suggesting that traditional explicit instruction can negatively affect adaptation to novel task demands. During Transfer 2 (attentional loading), the AI group made more putts than expected while the TEI and CTRL groups made fewer. These results suggest that when instruction is given, the length of such instruction may degrade performance under secondary-task attentional loading. Moreover, the use of analogy instruction may confer an additional benefit compared to an equivalent-length explicit instruction.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

Introduction

Traditional explanations of motor skill learning have been founded on an assumption that new skills are learned explicitly over time, in a process in which learners accumulate rules about the performance of a task and progress through the specific stages of learning. For example, Fitts and Posner (1967) described this learning progression as being comprised of cognitive, associate, and autonomous stages. More recently, motor learning researchers have highlighted the distinction between the roles of declarative and procedural knowledge in motor skill learning (e.g., Maxwell, Masters, & Eves, 2003). Declarative knowledge is information about a task that can be readily verbalized by the learner. It is commonly described as *knowing what* to do. In contrast, procedural knowledge describes information that is not readily verbalizable but nevertheless guides the learner's actions in performing a movement skill. It is often described as *knowing how* to do something. Masters and colleagues (e.g., Masters, 1992; Maxwell, Masters, & Eves, 2000) have drawn parallels between *explicit learning* and the accumulation of declarative knowledge. Specifically, they have suggested that explicit motor learning is marked by what they refer to as *hypothesis testing*, which consists of conscious efforts to identify rules, facts, and other declarative information to assist in performance (Maxwell, Masters, Kerr, & Weedon, 2001). From this perspective, *implicit learning* has been described as relying on procedural knowledge to guide performance obtained without explicit and conscious effort to acquire declarative knowledge.

A small body of motor learning research suggests that instructional approaches thought to promote implicit learning facilitate motor skill retention and transfer compared to explicit *rule-driven* instructions, particularly under conditions of distraction or increased pressure (e.g., Masters & Poolton, 2012; Poolton, Masters, & Maxwell, 2005). It is thought that explicit instruction strategies lead to an overreliance on working memory, which subsequently breaks down when additional processing demands are introduced during performance. Implicit instruction strategies are based upon the notion that declarative and procedural knowledge can be acquired independently (Maxwell, Masters, and Eve, 2003). For example, a novice golfer putting on a slope might adjust his or her alignment to compensate for the effects of gravity without realizing it.

Previous research has revealed several benefits from implicit instruction of motor skills compared to explicit instruction. These include superior performance under conditions of increased cognitive demand (Masters, 1992), pressure (Maxwell, Masters, Kerr, & Weedon, 2001), and physiological fatigue (Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007) as well as improved retention over time (Poolton, Maxwell, & Masters, 2007), decision-making under time constraints (Masters, Poolton, Maxwell, & Raab, 2008), and movement form and accuracy (Capio et al., 2011). Masters and Maxwell (2008) suggested that these benefits can be explained using *Reinvestment Theory* (Masters, 1992; Masters, Polman, & Hammond, 1993), which argues that the conscious use of declarative knowledge disrupts normally automated motor processes and degrades performance. From a practical point of view, these benefits are important to athletes and other performers who face situations requiring them to retain skills over a long period of time, make decisions under time constraints, and perform under conditions of increased pressure.

Previous research on implicit and explicit motor skill instruction has typically used one of three approaches thought to promote implicit learning (for a review, see Masters & Poolton, 2012). The first involves practicing under dual-task conditions, which requires the learner to perform the primary task concurrently with a secondary task. Secondary tasks have typically involved auditory tone or wordmonitoring, number generation, or random letter generation. Dual-task conditions during acquisition are thought to promote implicit learning for the primary task by imposing an additional attentional load which prevents explicit processing of declarative knowledge related to the primary task. For example, Masters (1992) found that dual-task practice facilitated the performance of a golf putt compared to single-task practice in a subsequent increased-pressure testing setting. Masters concluded that dual-task practice prevented the accumulation of and reliance on declarative knowledge.

The second method used to promote implicit learning is the so-called *errorless learning* protocol. An errorless learning protocol designs the practice setting so that the likelihood of errors is dramatically reduced during early learning. In contrast, an *errorful learning* condition faces a more challenging practice setting. Typically, errorless learning conditions begin practice facing only minimal challenges related to meeting tasks demands and then face progressively more challenging conditions as practice progresses. For example, participants learning to throw overhand to several targets might begin with the largest target and only move to progressively smaller ones as they gain proficiency (Capio et al., 2011). The errorless learning approach is thought to reduce explicit hypothesis testing and rule formation during practice because the high likelihood of success reduces the need for explicit strategies for adjusting movement patterns. In contrast, the errorful learning condition promotes explicit processing and the accumulation of declarative knowledge as learners attempt to correct their errors. One study (Maxwell et al., 2001) compared an errorless learning group that practiced a golf putt progressing from short to longer distances (i.e., 25, 50, 75, 100, 125, 150, 175, and 200 cm) to an errorful learning group that practiced the opposite progression and found that the errorless condition facilitated transfer under a distracting condition. Additionally, the errorless learning group recalled fewer explicit rules related task performance when compared to the errorful learning group.

The third method thought to promote implicit learning employs instructions consisting of a brief analogy designed to convey the critical movement elements for the task. Examples of analogy instruction include telling swimmers to "glide like a torpedo" or basketball players to follow-through when shooting as though they are "putting cookies in a cookie jar". Although analogy instruction is technically not a form of implicit instruction, Masters and Liao (2003) suggested that it promotes implicit processes by *chunking* several procedural elements of complex movement. Komar et al. (2014) also noted that analogy instruction facilitates the learning complex motor skills by serving as a "biomechanical metaphor" to package information about task-relevant rules, cues, and knowledge. Such *packaging* would presumably reduce the amount of declarative knowledge accumulated during practice. One study (Liao & Masters, 2001) compared dual-task practice, explicit instruction, and analogy instruction conditions that practiced a table tennis topspin forehand. The analogy instruction informed participants to *move the bat as if they were moving it up the hypotenuse of a right triangle*. Results showed that the dual-task practice and analogy instruction conditions facilitated transfer performance under secondary task loading and resulted in the recall of fewer explicit rules. The authors concluded that analogy instruction is effectively equivalent to implicit instruction.

Statement of the Problem

Despite the evidence showing a learning benefit for implicit or analogy instruction, previous research examining this phenomenon has a glaring limitation. Specifically, comparisons between explicit instruction conditions and those thought to promote implicit processes have typically confounded the instructional approach with the amount of information presented in the instructions. For example, analogy instruction participants have been asked to memorize a single statement that is relatively brief and easy to recall while explicit instruction participants have typically been asked to memorize lists of six (Poolton et al., 2006), eight (Lam, Maxwell, & Masters, 2009), or 12 (Liao & Masters, 2001) rules related to task performance. In one study that matched the amount of instruction (Schucker, Ebbing, & Hagemann, 2010) for learning to swing a golf club, no performance differences were found either during practice or upon transfer to a increased pressure situation. Although this finding suggests that analogy instruction advantages disappear when equivalent instructional information is presented, it may also be related to the use of an extraordinarily large number of instructions (30) that simply overloaded both conditions. Thus, it is still unknown if the previously observed benefits of analogy instruction compared to explicit instruction were plausibly due to the number of instructions used in that research. One approach to examining this question is to simply reduce the number of rules presented in explicit instructions so that they present a similar amount of information as is contained in analogy instructions. Such a reduction would eliminate the confounding of amount of information and instructional approach. Moreover, the comparison of a *reduced-rule* explicit instruction condition to a traditional explicit instruction condition would help clarify whether rule listing at the end of a study is tied to the number of explicit instructional items given to the learner at the start. Finally, such an approach would also better reflect the way in which coaches often teach learners how to perform a new task. Although Liao & Masters (2001) noted the practicality of analogy instruction, the comparison to explicit instruction is unfair in this regard because few instructors would actually present a novice with 12 new things to learn at once.

Purpose of the Study

The purpose of this study was to compare the effects of analogy instruction on the performance and learning of a motor skill to those of explicit instruction consisting of a single statement (i.e., an equivalent amount of instruction). A secondary purpose was to compare analogy and reduced-rule explicit instruction to the traditional explicit instruction that included six rules (Poolton, Masters, & Maxwell, 2005).

Hypotheses

H1. The Analogy Instruction (AI) and One-Rule Explicit Instruction (OREI) groups will make more putts than the Traditional Explicit Instruction (TEI) and control (CTRL) groups during acquisition.

H2. The AI and OREI groups will be significantly more accurate and consistent on measurable putts that miss than the TEI and CTRL groups during acquisition as indicated by *x*- and *y*-direction constant error (CE), absolute constant error (ACE), and variable error (VE), and radial error (RE).

H3. The AI and OREI groups will have fewer putts outside the camera viewing area (OVA) than the TEI and CTRL groups during acquisition.

H4. The AI and OREI groups will make more putts than the TEI and CTRL groups during the first transfer test.

H5. The AI and OREI groups will be significantly more accurate and consistent on measurable putts that miss than the TEI and CTRL groups during the first transfer test as indicated by *x*- and *y*-direction constant error (CE), absolute constant error (ACE), and variable error (VE), and radial error (RE).

H6. The AI and OREI groups will have fewer OVA putts than the TEI and CTRL groups during the first transfer test.

H7. The AI and OREI groups will make more putts than the TEI and CTRL groups during the second transfer test.

H8. The AI and OREI groups will be significantly more accurate and consistent on measurable putts that miss than the TEI and CTRL groups during the second transfer test as indicated by x- and y-direction constant error (CE), absolute constant error (ACE), and variable error (VE), and radial error (RE).

H9. The AI and OREI groups have fewer OVA putts than the TEI and CTRL groups during the second transfer test.

H10. The AI and OREI groups will show a significantly lower index of redundancy during the secondary letter generation task than the TEI and CTRL groups during the second transfer test.

H11. The AI and OREI groups will commit significantly fewer errors during the secondary letter generation task than the TEI and CTRL groups during the second transfer test.TEI.

H12. The AI, OREI, and CTRL groups will list fewer explicit rules than the TEI group.

Assumptions

1. Participants were naïve to the purpose of the study.
2. Participants had no experience with the experimental task and no formal training experience designed to improve golf putting performance.
3. Participants performed the experimental task to the best of their ability throughout the entire experiment.

Limitations

1. The study was conducted under simulated putting conditions in a laboratory setting.
2. Participants were asked to learn the task of golf putting over two days, far less time than an individual who wishes to learn the task for practical purposes.
3. The data collector was not blind to the purpose of the study.

Delimitations

1. Participation was voluntary.
2. The sample consisted of undergraduate and graduate students from a southeastern university in the United States.
3. All participants were right-handed.

Definitions of Terms

Absolute Constant Error (ACE): The absolute value of CE for each subject; a measure of amount of bias without respect to its direction (Schmidt & Lee, 2011).

Analogy Instruction: Providing a learner with an analogy (e.g., "move the bat as if traveling up the side of a mountain" in ping pong or "glide like a torpedo" in swimming) as an instructional tool in order to invoke implicit learning processes. The analogy is thought to act as a heuristic that conveys task-relevant rules, cues, and knowledge (Komar et al., 2014).

Acquisition: The initial phase of a motor learning study during which the participant is introduced to the task and completes practice trials (Schmidt & Lee, 2014).

Attentional Capacity: The overall pool of attentional resources that a person possesses. This pool requires conscious effort to manage and has a limited capacity for information processing (Knowles, 1963).

Attentional Load: Any task, cognitive or motor, that causes a reduction in attentional capacity. Implicit and explicit learners are often trained or tested under a dual-task condition, which provides an additional attentional load in comparison with a single-task condition (Masters, 1992).

Auditory Secondary Task: A secondary task in the dual-task paradigm that consists of listening and responding to an auditory stimulus. Examples can include word monitoring in which a participant is asked to monitor a list of random words for an instance of a particular word (e.g., Beilock & Carr, 2001) and tone monitoring in which a participant is asked to respond to a tone or count a series of tones (e.g., Maxwell, Masters, Kerr, & Weedon, 2001).

Automatic Processes: cognitive aspects of movement production that are involuntary, fast, and do not require attention for execution. Motor skills are thought to rely on more automatic processes with practice (Schmidt & Lee, 2011).

Biomechanical Metaphor: A synonym for analogy instruction in motor learning. The analogy is biomechanical in that it describes fundamental aspects of movement and acts as a metaphor by comparing two seemingly unrelated objects (Masters, 2000).

Breaking Putt: A putt in which the golf ball moves laterally (i.e., left-to-right or right-to-left) as a result of putting on a sloped surface; related to the amount of force with which the ball is struck (Wilson & Pearcy, 2009).

Choking: The failure of normally expert skill under conditions of pressure (Baumeister, 1984; Beilock & Carr, 2001).

Chunking: In analogy learning, a term used to describe the repackaging of task-relevant rules or knowledge into a single heuristic. It is thought that information that is chunked together will reduce the amount of information consciously processed in working memory (Masters & Liao, 2003; Masters & Maxwell, 2004).

Constant Error (CE): With respect to sign, the average error of a set of scores from a target value; a measure of average bias (Schmidt & Lee, 2011).

Controlled Processes: cognitive aspects of movement production that are voluntary, slow, and require attention for execution. Motor skills are thought to rely on more controlled processes in the early stages of learning (Schmidt & Lee, 2011).

Declarative Knowledge: Knowledge that is associated with hypothesis testing and consists of rules, facts, and information that is consciously processed, able to be articulated, and easily transmitted to others, (Masters, 1992).

Dual-Task Paradigm: A procedure that requires an individual to perform two tasks simultaneously (i.e., a primary task and a secondary task) in order to assess attentional demand on the primary task or compare performance to single-task conditions (Masters, 1992).

Errorful Learning: Performing in a learning environment in which increased errors are made early in practice but reduced errors are made later in practice, typically by progressing from difficulty levels that are high to low. This method of learning is thought to invoke explicit processes (Maxwell et al., 2001).

Errorless Learning: Constraining the learning environment in such a way that the learner makes fewer errors early in learning, typically by progressing from difficulty levels that are low to high. This method of learning is thought to invoke implicit processes (Maxwell et al., 2001).

Evaluative Threat: A context in which the self can be judged negatively by others. Evaluative threat is one method used in psychological research to increase feelings of anxiety or pressure (Baumeister & Showers, 1986).Also known as social-evaluative threat.

Explicit Knowledge: Knowledge that is associated with hypothesis testing and consists of rules, facts, and information that is consciously processed, able to be articulated, and easily transmitted to others, (Masters, 1992).

Explicit Learning: Learning that occurs within conscious awareness and is associated with high amounts of verbalizable knowledge (Reber, 1993). Also known as conscious learning (Lewicki, Hill, & Czyzewska, 1992) or S-Mode learning (Hayes & Broadbent, 1988).

Hypothesis-Testing: A strategy used during motor skill learning in which the performer makes judgments about how to best perform the task by selecting aspects of successful attempts and avoiding aspects of unsuccessful attempts. A conscious effort is made to identify rules, facts, or knowledge that will assist in task performance. Attempts that are high in error are likely to feature more hypothesis-testing than attempts that are low in error (Maxwell, Masters, Kerr, & Weedon, 2001).

Implicit Knowledge: Knowledge that is outside of conscious awareness and thus unable to be articulated to others (Masters, 1992).

Implicit Learning: The acquisition of skills in the absence of explicit knowledge of the underlying information that guides performance (Reber, 1993). Also known as nonconscious learning (Lewicki, Hill, & Czyzewska, 1992) or U-Mode learning (Hayes & Broadbent, 1988).

Information: That which removes or reduces uncertainty. The binary digit, or bit, is the unit most often used in the measurement of information and uncertainty. The value *H* represents the amount of uncertainty or information, expressed in bits (Attneave, 1959).

Inherent Feedback: Sensory information about a movement that is always available after the movement is produced (Schmidt & Lee, 2013).

Learning Effect: A permanent change in motor behavior that must be inferred from testing (Schmidt & Lee, 2013).

Number Generation: A secondary task used in the dual-task paradigm that requires participants to generate numbers out loud verbally, either in a random order or a mathematical sequence. An example would be counting backward by three's from 1100 (Liao & Masters, 2001).

Outside the Viewing Area (OVA): The viewing area was defined as the width and length of the putting platform that was visible to the camera that was mounted overhead in the current study. This area was approximately 100 cm wide and 200 cm long. Any putt that came to rest outside of this area (i.e., too far left, right, short, or long) was labeled as an OVA putt.

Performance-contingent reward: Something that is given or withheld based on the quality of performance on a task, often in the form of a financial incentive. Performance-contingent rewards constitute one method used in psychological research to increase feelings of anxiety or pressure (Baumeister & Showers, 1986).

Performance Effect: A temporary change in motor behavior that can be observed and measured during a practice session (Schmidt & Lee, 2013).

Primary Task: In a dual-task paradigm, the task that is of primary interest to the researcher. Attentional allocation or performance on the primary task may be measured and subsequently compared to single-task conditions (Masters, 1992).

Procedural Knowledge: Knowledge that is outside of conscious awareness and thus unable to be articulated to others (Masters, 1992).

Radial Error (RE): The square root of the average squared deviations of a set of values from a target value; typically used as a measure of tracking proficiency (Schmidt & Lee, 2011).

Randomness: Unpredictability in an event or series of events. A standardized mathematical definition of randomness has been difficult to create because of the varying methods of testing randomness. For example, a repeating sequence of the alphabet would seem completely random if individual letters were analyzed but be considered nonrandom if pairs of letters are analyzed. (Attneave, 1959).

Random Letter Generation (RLG): A secondary task utilized in the dual-task paradigm of implicit motor learning protocols that requires participants to say a random letter from the alphabet at a specified pace (Baddeley, 1966; Masters, 1992).

Redundancy: The compliment to randomness. In information theory, redundancy refers to the difference in the number of bits used to transmit a message and the number of bits containing actual information in the message. The higher the redundancy, the more the source of information can be compressed. For RLG, the redundancy of a sequence of letters can be calculated as a measure of task performance (Attneave, 1959; Baddeley, 1966; Reza, 2010).

Reinvestment Theory: A theory of motor control regarding conscious attention to movement which suggests that automated processes can be disrupted if consciously-accessed, task-relevant declarative knowledge is used to perform a motor task (Masters, 1992; Masters & Maxwell, 2008; Masters, Polman, & Hammond, 1993)

Retention: An assessment of performance following a period without practice to determine the degree of learning that took place during acquisition (Schmidt & Lee, 2014).

Secondary task: In a dual-task paradigm, the task that a participant is asked to perform in addition to the primary task of interest. The secondary task may be used to assess attentional allocation on the primary task or place an additional attentional load on the performer. Some common secondary tasks include tone monitoring, random letter generation, or counting backwards by a certain interval (Lam, Maxwell, & Liao & Masters, 2001; Masters, 2009; Maxwell, Masters, Kerr, & Weedon, 2001; Poolton, Masters, & Maxwell, 2007).

Social Comparison: The act or context of comparing the self with others on some measure. Social comparison is one method used in psychological research to increase feelings of anxiety or pressure (Baumeister & Showers, 1986).

Stages of Learning: In motor skill acquisition, the steps that a person goes through while progressing from novice to expert performance. These may include the cognitive, associative, and autonomous stages (Fitts & Posner, 1967).

Transfer: An assessment of learning requiring participants to perform a slight variation of the skill practiced during acquisition (Schmidt & Lee, 2014).

Variable Error (VE): The standard deviation of a set of scores about the subject's own average score; a measure of movement consistency (Schmidt & Lee, 2011).

Working Memory: A brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning. It simultaneously stores and processes information and consists of the Central Executive, the Visuospatial Sketchpad, and the Phonological Loop. Synonymous with short-term memory (Baddeley, 1992).

X-dimension Error: On misses, the distance from the center of the cup to the center of the golf ball in an imaginary plane stretching the width of the putting carpet. Positive numbers indicate a putt that missed to the right of the hole while negative numbers indicate a putt that missed to the left of the hole.

Y-dimension Error: On misses, the distance from the center of the cup to the center of the golf ball in an imaginary plane stretching the length of the putting carpet. Positive numbers indicate a putt that was long of the hole while negative numbers indicate a putt that was short of the hole.

CHAPTER 2

Review of Literature

Human beings are able to learn and adapt to their environment via implicit or explicit processes (Reber, 1967). Implicit learning refers to the process of acquiring procedural knowledge without an accumulation of declarative knowledge and explicit learning refers to situations in which both procedural and declarative knowledge are accumulated (Masters, 1992). Squire (1987) described procedural knowledge as "knowing how" and declarative knowledge as "knowing that". For example, a person can possess extensive procedural knowledge about how to walk or run without being able to verbalize declarative knowledge about the biomechanical principles of these movements. Conversely, a person might possess declarative knowledge about how to move the pieces on a chess board without being able to utilize procedural knowledge in order to place the game of chess well. According to some researchers, declarative knowledge depends upon the availability of working memory while procedural knowledge does not (Berry & Broadbent, 1988; Roberts & MacLeod, 1998). With practice, declarative knowledge about a task may be subsumed by procedural knowledge as control becomes more reliant on automatic processes.

Although providing an operational definition of implicit learning has proven challenging, it is generally agreed that implicit learning is the antithesis of explicit learning, during which purposeful hypothesis testing is used to discover rules that govern effective and ineffective behaviors (Frensch & Runger, 2003; Masters & Poolton, 2012). Implicit learning is driven by unconscious processes, which require little or no mental capacity, while explicit learning is driven by conscious processes, which are constrained by the capacity of the brain to process information (Frensch & Runger, 2003; Kahneman, 1973). In addition a reliance on the accumulation of declarative knowledge associated with explicit learning can lead to performance breakdown under conditions of distraction or pressure (Poolton, Masters, & Maxwell, 2005). As a result, implicit learning strategies are generally regarded as advantageous when compared with explicit learning strategies (Masters & Poolton, 2012).

Implicit learning was first demonstrated in psychological studies of complex cognitive tasks, such as identification of artificial grammar strings and properties of synthetic language (e.g., Reber, 1967, 1976; Reber, Kassin, Lewis, & Cantor, 1980) and manipulation of dynamic systems (e.g., Berry & Broadbent, 1984). Throughout implicit learning literature, a common theme is incidental learning (Thorndike & Rock, 1934), in which participants learn complex patterns (i.e., demonstrate improvements in performance) without realizing that they are learning the pattern that is present (Lewicki, Czyzewska, & Hoffman, 1987; Reber et al., 1980; Reber, 1993). Reber (1967) found that participants who learned synthetic language via "discovery" methods of trial-and-error were able to identify more incorrect examples of grammar compared with participants who received explicit rules to follow. Berry & Broadbent (1988) asked participants to control a dynamic computer program that featured a large number of input variables that could be manipulated in order to produce a specific output. They found that participants who were asked to learn the program implicitly demonstrated superior performance and less declarative knowledge than participants who were given explicit instructions about the relationships between variables. While implicit learning was originally demonstrated in psychological studies, it was later applied to studies of motor learning as well.

Motor Performance versus Motor Learning

Before discussing studies of skill acquisition related to implicit motor learning strategies, it is important to distinguish between the concepts of motor performance and motor learning.

Performance consists of temporary changes in behavior that can be measured or observed during instruction while learning is an internal process that is not directly observable and must be inferred from changes in performance after the conclusion of instruction (Schmidt & Lee, 2014). Performance can influenced by temporal factors such as motivation, fitness, or fatigue, while learning is more permanent and less susceptible to such factors. This distinction is important because some studies may indicate significant differences in performance during acquisition (i.e., practice) while yielding no significant differences in learning on tests of retention or vice versa.

Traditional Explanations of Motor Skill Acquisition

Fitts and Posner (1967) describe the learning of a motor skill in three stages: cognitive, associative, and autonomous. Such stages may be distinguished by the type of knowledge or processing used by the performer. In the cognitive stage, declarative knowledge is acquired and observable performance is slow and inconsistent. Since performance at this stage is reliant upon conscious processing, a large amount of attentional resources is required. In the associative stage the performer possesses both declarative and procedural knowledge and performance is improved yet inconsistent. In the autonomous stage, procedural knowledge is largely utilized and performance is fast, efficient, and smooth and requires few attentional resources due to the use of automatic processes. Improvements in the autonomous stage may continue indefinitely. Anderson (1982) made a similar distinction between stages of learning when describing the declarative stage of skill acquisition, in which facts about the performance of a skill are initially acquired and interpreted, and the procedural stage, in which knowledge about the skill is directly applied to performance. In the declarative stage, verbal facts are often rehearsed over and over in order to keep these facts in working memory while this rehearsal is not necessary in the procedural stage. According to these two models, declarative knowledge acts as a prerequisite for procedural knowledge and learners must progress through these early declarative stages before reaching later stages that are characterized by proceduralized performance. However, models of implicit motor learning suggest that declarative and procedural knowledge can be acquired in parallel.

Implicit Motor Skill Acquisition

Unlike proponents of traditional explanations of motor skill acquisition, proponents of implicit motor learning subscribe to the belief that declarative and procedural knowledge can be acquired independently and in parallel (Maxwell, Masters, & Eves, 2003). Implicit motor learning consists of instruction or strategies that allow the learner to increase his or her procedural knowledge of a task and subsequent use of automatic processes without an accumulation of declarative knowledge that would typically be present in the early stages of learning. These implicit learning methods have translated into benefits in previous research when compared with explicit learning, including better performance under cognitively-demanding and anxiety-producing conditions (Hayes & Broadbent, 1998; Masters, 1992; Maxwell, Masters, Kerr, & Weedon, 2001), superior skill retention over time (Poolton, Maxwell, & Masters, 2007), superior performance under physiological fatigue (Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007), superior performance under conditions involving decision-making under time constraints (Masters, Poolton, Maxwell, & Raab, 2008), and greater gains in movement form and accuracy (Capio et al., 2011). Methods of implicit learning have been investigated in motor learning literature for both laboratory tasks and sport-related tasks. In the sections that follow, each of the following methods will be described and discussed: (a) incidental learning of patterns in laboratory tasks, (b) the dual-task paradigm in golf putting, errorless learning in sport-related tasks, and analogy learning in sport-related tasks.

Incidental learning of patterns in laboratory tasks. Studies of laboratory tasks that involve the learning of a pattern are inherently similar to those conducted by Reber (1976) and Barry and Broadbent (1988) in the sense that they require participants to learn about relationships or a system that is based on rules or repetition via incidental (i.e., discovery) learning. For example, in a study by Wulf and Schmidt (1997), participants practiced pursuit-tracking task for 50 trials on each of 5 days. The wave patterns consisted of three segments. While the first and third segments were generated randomly from one trial to the next, the middle segment was the same pattern for each trial. During retention tests and transfer tests featuring novel speed scaling, the repeated segment was produced more accurately than random segments, without participants being aware of the segment characteristics or that fact that it was repeated. Similar results have also been demonstrated with a serial reaction time task in which participants who practiced an implicit pattern had faster reaction times when compared with those who practiced a sequence with no pattern (Nissen, Willingham, and Hartman, (1989).

While Wulf and Schmidt (1997) demonstrated that implicit learning of a pattern is possible via a within-subjects design, Green and Flowers (2003) utilized a between-subjects design to compare implicit and explicit learners on a task that involved using a joystick to "catch" a light on the screen. An implicit group was given no instructions on how to perform the task while an explicit group was given prior rules about how to perform the task. While both groups improved with practice during acquisition, the explicit group demonstrated inferior performance compared to the implicit group, particularly during the early stages of acquisition. The authors attributed this finding to the challenges of attempting to recall and apply a set of rules to a complex visual task.

Such studies demonstrate that the results of psychological studies of implicit learning such as those related to grammatical systems or dynamic computer systems can be extended to motor tasks as well. However, it is difficult to compare these results to sport skills and other complex motor tasks. These types of tasks are "truly" learned implicitly in the sense that participants are unaware that a pattern exists and unaware that their performance is improved when the pattern is present compared to when it is absent. In studies of sports tasks, participants are always aware of the relationship between their movements and performance outcomes as a result of inherent feedback.

Implicit learning via the dual-task paradigm. The dual-task paradigm is thought to induce implicit processes by preventing participants from engaging in hypothesis-testing and accumulating declarative knowledge while putting. If enough resources were devoted to the secondary task, there would be little resources left to devote to putting. The first study to examine implicit motor learning via the dual-task paradigm was that of Masters (1992), where groups were asked to putt under dual-task conditions involving a random letter generation (RLG) task or explicit conditions in which participants were given a set of putting instructions and told to follow them precisely. . Tests were conducted under stressful conditions, induced by a combination of evaluation apprehension and financial inducement. Participants' heart rates were monitored as an indication of apprehension. Performers in the implicit condition were less likely to fail under pressure and also reported fewer explicit rules related to putting. The implicit processes that were induced by the dual-task paradigm during training were more resistant to the effects of emotional factors (e.g., anxiety) that can disrupt performance when compared with the explicit processes associated with explicit instruction (Rathus et al., 1994).

Several studies have extended, replicated, or challenged Masters (1992) findings. Hardy, Mullen, and Jones (1996) argued that because participants in the implicit learning group were asked to perform RLG during learning but not during testing, there may have been a decrease in difficulty from learning to testing that could account for the result rather than the differences in learning style but found that the implicit learning group continued to show improved performance over the explicit learning group, even when tested under dual-task conditions. However, this result could have also been due to participants' desensitization to the secondary task as a result of extensive practice during acquisition. Bright and Freedman (1998) also replicated Masters (1992) and included a group that was trained and tested under dual-task conditions but found no evidence that anxiety differentially affects individuals who have learned a motor skill under dual-task versus explicit conditions.

Another issue with regard to using a dual-task paradigm in the aforementioned studies of implicit learning is the selection of a concurrent secondary task. As Seger (1994) notes, there are a number of different secondary tasks available to researchers, including tone counting, memory load, timed response, or random number generation; these different tasks may affect different mental processes, making comparisons across studies problematic. As results by Gray (2004) indicate, the relevance of the secondary task can also affect performance. Gray found that novices who were explicitly trained on a simulated baseball training task were unaffected by secondary task loading if the task was relevant to the primary task. However, if the secondary task was extraneous, novices' performance was negatively affected. As such, it seems that incorporation of the dual-task paradigm leads to several confounding factors and future research should consider using other methods besides secondary task loading to encourage implicit learning during training or distraction during testing.

Mullen and Hardy (2000) examined the ramifications of skill level and changing the secondary task., Experienced golfers were asked to putt under dual-task conditions in which the secondary task was either task-relevant (reciting instructions related to putting) or task-irrelevant (RLG). This group of participants was divided based on putting performance under baseline conditions and tested under high anxiety and low anxiety conditions. Anxiety was induced by informing participants that their putting would be evaluated by a golf professional and that their performance would be compared to that of other golfers for monetary award. Interestingly, results indicated that poorer putters were not affected by increases in anxiety, while better putters were not only negatively affected by increases in anxiety but also negatively affected by both dual-task conditions when compared with baseline performance. Implicit processes that may have been present under dual-task conditions were not able to prevent choking in better putters.

Mullen, Hardy, and Oldham (2007) suggested that the amount of practice and the timing of testing might affect results. Participants were tested under one of the following conditions: Explicit learning achieved by reading a set of instructions about how to putt or implicit learning through RLG. In variations on these two basic conditions, implicit learners in one RLG group were tested once under anxiety-producing conditions while learners in another RLG group were tested twice under anxiety-producing conditions (once after 160 trials and one after 500 trials). Additionally, these two groups were asked to perform RLG during the anxiety testing to maintain consistent levels of task difficulty from acquisition to testing, while another RLG group was not asked to do so. Anxiety was induced through the prospect of financial incentives, and participants were told that they would be judged based on video recording of their performance and subsequent judging by a expert golfer. Levels of anxiety were measured using the Competitive State Anxiety Inventory (CSAI-2) (Martens, Burton, Vealey, Bump, & Smith, 1990B). Results did not align with previous research and indicated similar levels of performance for all groups on the first anxiety test, suggesting that explicit knowledge may not have a detrimental effect early in the learning process. During the second test, each of the implicit groups showed improved performance regardless of whether or not they were asked to perform RLG while the explicit group showed a performance decrement.

Placing participants under testing conditions that are meant to induce choking is common in dual-task implicit learning literature. Previous research on sensorimotor skills (e.g., Beilock & Carr, 2001; Beilock, Wierenga, & Carr, 2002; Gucciardi & Dimmock, 2008) has demonstrated support for the idea that choking may be caused by the explicit monitoring of processes that normally occur automatically. Therefore, one may conclude that a skill which is learned implicitly will be less likely to fail under pressure. However, the concept of choking is problematic in that it is a subjective assessment of why performance failed. In addition, the methods used in previous literature have not been consistent. These have included financial incentives, video recording, and expert evaluation. A financial incentive may have mixed results regarding increased anxiety and proclivity to choking since the amount of the incentive can mean something different to each participant. Methods such as video recording (e.g., Beilock & Carr, 2001; Otten, 2009) and real or imagined expert evaluation (e.g., Masters, 1992; Bright & Freedman, 1998) seem effective at inducing increased anxiety and explicit monitoring, but the diversity in methods used across studies makes comparison difficult.

In Beilock and Carr (2001), performance under pressure was examined along with ways in which training conditions might ameliorate it. Participants trained under single-task, dual-task, or self-consciousness conditions and were then given low-pressure and high-pressure posttests. Under dual-task conditions, participants heard a series of recorded words and were asked to repeat the word "cognition" every time they heard it. Under self-consciousness conditions, participants were filmed by a video camera and told that videos would be used by golf teachers and coaches in order to better understand how putting is learned. While choking was unaffected by dual-task conditions, it was ameliorated by self-consciousness training. Since choking results from explicit monitoring, which results from self-consciousness and performance anxiety, it was concluded that practice under conditions that induce self-consciousness facilitated a desensitization to the mechanisms underlying choking.

In a similar study involving golf putting, Beilock, Wierenga, and Carr (2002) found that experts demonstrated similar levels of performance from single-task to dual-task conditions, improved word recognition on an auditory secondary task, and decreased episodic memory when compared with novices. However, when experts were ask to putt with an irregular putter, each of these results were found to be similar with those of novices. It was also found that trained novices showed results that were intermediate between untrained novices and experts. These results demonstrated evidence for stages of learning and the idea that a disruption in the automatic processes of expert performers can lead to a regression to earlier stages of learning.

While each of these studies has demonstrated the benefits of implicit learning under conditions of increased psychological stress, some of their conclusions are problematic. As authors such as Beek (2000) have pointed out, the nature of dual-task training lacks in practical application to typical learning conditions. Some of the aforementioned studies (e.g., Masters, 1992; Hardy, Mullen, & Jones, 1996) have used dual-task conditions during training or testing to make claims about the benefits of implicit learning against choking. However, results regarding the use of the dual-task paradigm to prevent choking have been mixed. In other studies, dual-task protocols have had a detrimental effect on learning (Dienes, Broadbent, & Berry, 1991; MacMahon & Masters, 2002; Maxwell, Masters, & Eves, 2000; Pew, 1974).

Implicit learning via errorless protocols. Errorless learning consists of constraining the early learning environment in order to reduce the number of errors committed while errorful learning presents a early learning environment that is challenging and characterized by many errors. Errorless learning is thought to be an implicit form of learning because it is defined by less hypothesis-testing and defined by less verbalizable rules while errorful learning is hypothesis-driven in order to correct errors and results in an increased accumulation of declarative knowledge. In a study by Maxwell et al. (2001), errorless learners were asked to start closer to the target and move farther away and subsequently had a reduced number of errors when compared with errorful learners. Errorless learners were asked to start farther away from the target and move closer and demonstrated the opposite result. When placed under the imposition of a secondary task load during testing, errorful learners displayed performance decrements while errorless learners did not. These results were attributed to the resiliency of implicit processes to distraction. In addition, errorful learners listed more explicit rules than errorless learners on verbal measures, suggesting a greater accumulation of declarative knowledge. In general, learners who have committed an error on the previous trial are thought to engage in more hypothesis-testing and conscious monitoring of movements than those who have not committed an error (Koehn, Dickinson, & Goodman, 2008). Evidence for this conclusion has been demonstrated in golf putting using probe reaction times (Lam, Masters, & Maxwell, 2010). Lengthened reaction times and increased movement times occurred after trials in which participants committed an error, relative to trials that were performed successfully. These results suggest an increase in cognitive demand after errors, corresponding to increased hypothesis-testing.

As indicated by Masters & Poolton (2012), verbal protocols that require rule-listing may not be sensitive enough to fully gauge the verbalizable knowledge that a participant possesses and are thus used as a general guide or method check. Where possible, more sophisticated methods of assessing implicit learning such as measuring EEG co-activation between verbal and motor areas of the brain should be used (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011). Zhu et al. (2011) found that participants who learned a golf putting task implicitly via errorless protocols demonstrated less co-activation among the aforementioned brain regions during practice and a pressured transfer test when compared with individuals who learned explicitly via errorful protocols. These results suggest that explicit learners were engaging in more verbal-analytical processing of putting movements than implicit learners.

Previous research has also examined the effects of switching participants from implicit to explicit conditions during training. Poolton, Masters, and Maxwell (2005) suggest that the benefits of engaging implicit processes at the outset of skill acquisition remain even with the accumulation of explicit knowledge later in learning. Participants were asked to putt from different distances under Explicit (E) conditions, instructions relating to proper putting technique were given to participants at the beginning, or Implicit-Explicit (I-E) conditions, in which participants initially learned how to putt using an errorless putting protocol and then the explicit instructions were presented later in learning. Participants were tested under the additional attentional load of dual-task conditions. Performance of those in the I-E condition was unaffected by the additional load while performance of those in the E Condition deteriorated. These results suggest that an uninstructed environment results in advantages early in learning by encouraging participants to use procedural knowledge to generate motor output.

In addition to the benefits of errorless learning under an additional attentional load, benefits have also been demonstrated under conditions of physiological fatigue. Both anaerobic (Poolton, Masters, & Maxwell, 2007) and aerobic fatigue (Masters, Poolton, & Maxwell, 2008) have been examined. According to evolutionary biology, implicit processes preceded explicit processes in our evolutionary history and are, thus, thought to be more stable and resilient to disruption (Reber, 1992). Following this principle, Participants learned a throwing task under either implicit or explicit conditions before fatiguing them and testing their subsequent performance. Learners performed a rugby pass under errorless (i.e., starting in close proximity and moving further away) training conditions or errorful (i.e., starting further away and progressively moving closer) training conditions and were fatigued anaerobically (Poolton, Masters, & Maxwell, 2007) aerobically (Masters, Poolton, & Maxwell, 2008). Results indicated that fatigue had no effect on participants in the implicit condition while participants in the explicit condition showed significant performance decrements as a result of fatigue. In a follow-up, participants were brought back after one-year to examine longitudinal performance. Results indicated that performance levels were maintained, suggesting retention in both groups. However, both the implicit and explicit group showed resilience to fatigue after one-year. These results suggest that time can act as a mediator between implicit and explicit modes of learning and declarative knowledge.

The benefits of errorless learning have also been demonstrated in children. Capio, Poolton, Sit, Holmstrom, and Masters (2011) describe Fundamental Movement Skills (FMS) as the basis for more complex movement in sports and a significant contributor to excellence in sports. In this study, the authors examined the development of FMS in a group 8-12 year old children. Participants were asked to perform an overhand throwing motion under one of two training conditions: (a) an error-reduced (ER) group in which the task difficulty was initially low and then incrementally raised by varying the target size and (b) an error-strewn (ES) group in which the task difficulty was initially high and then incrementally lowered via the same means. As a result of constraining the learning environment, ER participants demonstrated fewer absolute errors and greater gains in movement kinematics (i.e., form and accuracy) when compared with the ES group, and the ER group demonstrated better performance under a concurrent secondary cognitive task during transfer. As Capio et al. (2011) mention, one concern of research protocols that utilize errorless or errorful learning conditions is that of order effects. Learners under errorful conditions progress from easy conditions to hard conditions while learners under errorless conditions are typically performing under the most difficult conditions during the last portion of acquisition. Since transfer tasks often involve conditions of increased rather than decreased difficulty, errorless learners may have the benefit of experiencing difficult conditions most recently.

It has also been suggested that psychological mechanisms such as motivation and self-efficacy can play a role in errorless and errorful learning. In a study by Ong, Lohse, Sze, & Hodges (2013), participants were asked to perform a dart-throwing task under one of two conditions: errorless, in which they progressed from near-to-far, and errorful, in which they progressed from far-to-near. Results indicated that the errorless group did not make less errors during practice, confounding the protocol. In a second study, experimenters manipulated the size of the target rather than the target distance. Errorless learners threw to a large target while errorful learners threw to a small target. Both groups showed similar performance during practice, while the errorless group showed improved performance on retention and transfer tests. Additionally, the errorless group showed higher levels of motivation and self-efficacy, which may be an alternative explanation for the results of errorless learning benefits. The impact of psychological measures such as motivation, self-efficacy, or perceived competence in performing a task seems logical: if learners are achieving higher levels of success early in the task, they are more likely to continue performing as a result of the psychological ramifications of success. This explanation could be problematic for proponents of implicit learning as it seems challenging to tease apart these two competing explanations.

A general concern with regards to errorless and errorful learning protocols is the lack of a clear connection between these instructional methods and implicit or explicit processes. Errorless and errorful protocols do not necessarily correspond to implicit and explicit learning, respectively. An individual can learn a difficult task implicitly while making many errors, and he or she can also learn an easy task explicitly while making few errors. One may argue that these conditions are attempts to constrain the learning environment in a way that will be most appropriate for learners with regard to difficulty level and promote levels of motivation and self-efficacy that will be conducive to learning the task rather than attempts to induce implicit or explicit processes.

Implicit learning via analogy instruction. Studies of analogy learning as a form of implicit learning emerged from methodological and practical issues with prior studies of implicit learning that had used dual-task paradigms. It was suggested that this form of instruction would have more external validity for instructors in the real world. Analogy learning is thought to package information about performance more efficiently than explicit instruction and convey a large amount of information in a single statement, thus reducing the amount of declarative knowledge utilized. In a study by Liao & Masters (2001), participants were asked to play table tennis and were divided into three groups: implicit, analogy, and explicit learning. In the implicit learning group, participants were asked to perform under a concurrent secondary task. In the analogy group, participants were told to imagine performing a topspin forehand by imagining that they were moving the paddle up the hypotenuse of a right triangle. In the explicit learning group, participants were given a list of 12 basic techniques for hitting a topspin shot. Results indicated that the analogy and implicit learning groups accumulated less knowledge than the explicit group, and they showed less of a performance decrement under secondary loading when compared with the explicit group. In the second experiment, participants were tested under an anxiety-producing condition that featured false normative feedback, and results indicated that only the explicit group showed a performance decrement under this variation.

Law, Masters, Bray, Eves, and Bardswell (2003) tested participants under similar conditions using explicit instructions and the same right triangle analogy as Liao and Masters (2001) but placed participants under pressure by performing in the presence of three different audiences: neutral, supportive, and adversarial. Results indicated that analogy learners' performance was consistent under each of these conditions, while explicit learners ironically showed a performance decrement in the presence of a supportive audience. These results were interpreted as further evidence for analogy learners' limited explicit knowledge of movement mechanics and decreased conscious movement control when compared with explicit learners. However, it is unclear why explicit learners were not affected by adversarial audience as one might expect.

Other researchers have provided evidence disputing the benefits of analogy learning when compared with explicit learning. Koedijker, Oudejans, and Beek (2007) had participants practice a table tennis forehand shot using the right-angle triangle analogy or explicit instructions over extended number of practice trials (*N* = 10,000). While the analogy group showed small benefits early in learning, their performance plateaued around 1,400 trials and no subsequent differences were found between the two groups during practice trials, secondary task transfer trials, or pressured transfer trials. These results suggest that the advantages of analogy learning disappear after a relatively short period of time.

The interaction of analogy learning with other factors has been examined in previous literature. These factors include decision-making, attentional resource allocation, and an internal focus of attention. In a study of decision-making by Raab (2003), participants performed in low-complexity and high-complexity situations in basketball, handball, and volleyball. Within the context of sport, the authors argue that implicit learning must be further differentiated between implicit motor learning (i.e., movement production) and implicit cognitive learning (i.e., one's understanding of the connection between environmental stimuli and what action should be carried out) (Masters, Law, & Maxwell, 2002). These distinctions are referred to as motor-linked implicit learning and judgment-linked implicit learning, respectively. Previous research on implicit learning of motor skills has presented an ideology that less verbalizable knowledge is better for retention and learning. However, as the authors argue, in the realm of decision-making, more knowledge is better. The interaction of task complexity and learning processes was examined over the course of four experiments. Results indicated implicitly-learned decisions were better for low-complexity situations and explicitly-learned decisions were better for high-complexity situations. The authors conclude that previous research advocating primarily for the learning of motor skills through implicit means has neglected to consider the environment in which they will be used and thus overlooked the cognitive and decision-making components of open skills.

Decision-making and analogy learning was also examined in Poolton et al. (2006). Participants were taught a table tennis topspin forehand via an analogy or explicit instruction. In the analogy condition, participants were told to hit the forehand shot as if the paddle were travelling up the side of a mountain, and in the explicit condition, participants were given a list of six instructions to follow. In order to manipulate complexity, the color of the ping pong ball would change and determine the target of each trial. In the low-complexity condition, the side-color relationship remained the same, while the side-color relationship would switch after every two trials in the high-complexity condition. Results indicated that low-complexity decisions had no effect on the performance of either group while high-complexity decisions caused a performance decrement in the explicit learning group but not the analogy learning group. These results contrasted those of Raab (2003), who found a preference for implicit learning in low-complexity situations and a preference for explicit learning in high-complexity situations.

Masters et al. (2008) extended the research of Poolton et al. (2006) and addressed the potential confound that participants were required to hit to a central target during acquisition but targets that were left and right of center during decision-making trials. Conditions were the same as that of Poolton et al. (2006). During retention testing, participants were asked to hit to the same target as training, but during transfer testing, participants were asked to make low-complexity and high-complexity decisions by determining which target to hit based on the color of the ball. Results indicated that analogy learners had less movement-related knowledge than explicit learners, and performance was disrupted in the explicit condition but not the analogy conditions, thus replicating the results of Poolton et al. (2006). Kinematic analyses revealed that movement characteristics remained the same for both conditions on low-complexity trials, but both peak and average movement speed decreased and intertrial variability increased during high-complexity trials for the explicit group.

The interaction of analogy learning and attentional resource allocation during a task using probe reaction times (PRT) has also been examined. Lam, Maxwell, and Masters (2009) asked participants to perform a seated basketball shooting task under explicit learning conditions or analogy learning conditions. Performance was compared during acquisition, a delayed a retention test, and a pressured transfer test, and access to task-relevant declarative knowledge was examined for both groups. Results indicated no significant differences in performance between groups during acquisition and retention, but the explicit group experienced a decline in performance on the pressured transfer test when compared with their performance on the retention test. Analyses of PRT revealed that participants in each group allocated attentional resources equally, but analyses of declarative knowledge revealed that the analogy group had significantly less access to declarative knowledge of movement mechanics when compared with the explicit learning group.

In a study by Komar, Chow, Chollet, and Seifert (2014), analogy instructions that induced an internal focus of attention were used in learning breaststroke swimming. Quantitative changes (i.e., performance) and qualitative changes (i.e., movement form) in breaststroke swimming were compared between two groups: a control group that only received information relating to the goals of the movement and rules that were to be followed for executing the breaststroke and an analogy group that was given the same information along with an additional instruction, which was to "glide for 2 seconds with your arms outstretched." Results indicated that swimmers in the analogy condition showed increased movement efficiency and inter-limb coordination when compared with the control group.

Previous research has demonstrated the potential for analogy learning to act as an instructional strategy that induces implicit processes, as indicated by the decreased number of explicit rules list by analogy learners. In addition, previous research has demonstrated the benefits of analogy learning under various conditions involving additional attentional loading, increased pressure, and timed decision-making when compared with forms of explicit learning. These benefits have also been compared with other instructional strategies such as errorless learning and quiet eye training.

In a study by Orrell, Eves, and Masters (2006), analogy learners were compared with errorless learners and discovery learners on a balancing task that involved a stabilometer. In the analogy condition, participants were instructed to "pretend to be soldiers outside Buckingham Palace". This analogy was chosen based on pilot testing of the kinematics and the subsequent conclusion that the best performance would be achieved by facing forward and pointing the arms straight down beside the body. In the errorless condition, the potential amount of displacement of the stabilometer was gradually increased by lowering jacks underneath the platform. Each time that the jacks were lowered, the stabilometer was allowed to swing more freely and the amount of potential error was thus increased. Participants in the discovery group were instructed to "discover the rules of how to perform the task". Three criteria were used to examine the implicit nature of each condition: the accumulation of explicit rules, performance under secondary task loading, and durability over time. While the discovery learners accumulated more explicit rules than the other two groups, the balance performance of all groups improved with the imposition of a concurrent verbal task. All groups showed similar levels of performance during acquisition and retention, and all groups demonstrated durability over time based on a two-week delayed retention test. These results are in contrast with other implicit-explicit learning studies. One would expect the Explicit group to display a performance decrement when placed under secondary task loading since the secondary task is hypothesized to interfere with the retrieval of explicit knowledge. Additionally, implicit learning is thought to be more resilient over time when compared with explicit learning. These results suggest that learning a balance task is implicit in nature, regardless of learning conditions.

Quiet eye training has also been compared with analogy learning as a viable means of inducing implicit processes. Vine et al. (2013) examined the skill of golf putting in three training groups: an Explicit group that received six instructional rules, an Analogy group that received a single instruction in the form of an analogy, and a Quiet Eye (QE) group that received six rules related to gaze control. Participants performed 320 putts during acquisition followed by 60 total putts in an A-B-A (Retention-Pressure-Retention) design and were given measures of conscious processing and explicit rule accrual. Conscious processing was assessed via a version of the Conscious Motor Processing Subscale of the Movement Specific Reinvestment Scale (MSRS) adapted for putting. The QE group outperformed the analogy group during retention testing and outperformed both groups during a pressured transfer test. In addition, the QE group and Analogy group reported less conscious processing and fewer explicit rule accumulation than the explicit group. The authors concluded that Quiet Eye training is a viable means to implicit learning and that the superior attentional control of QE learners was responsible for differences in performance, particularly those found under pressure.

One problem with comparisons of analogy learners and explicit learners is that the amount of information presented to the participant is not balanced across conditions. For example, analogy learners are often asked to memorize and visualize a single statement that is relatively brief and easy to recall while explicit learners are asked to recall six (Poolton et al., 2006), eight (Lam, Maxwell, & Masters, 2009), or 12 (Liao & Masters, 2001) rules related to task performance. An alternative explanation for the results of such studies comparing analogy learning with explicit learning could be that explicit learners are simply required to manage a greater attentional load.

Attentional Capacity and Implicit/Explicit Learning

Much of the research on implicit motor learning strategies has demonstrated benefits under conditions of psychological or physiological stress when compared with explicit motor learning strategies. The superior performance of implicit learners occurs because they are less likely to engage in "reinvestment" of explicit knowledge (Masters, 1992; see Masters & Maxwell, 2008 for a review). In other words, implicit learners are less reliant on explicit cognitive processes in working memory. For example, expert performers who use explicit knowledge of movement mechanics in order to execute a skill can demonstrate performance decrements in the form of "choking", the failure of normally expert skill under pressure (Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992). When an individual consciously monitors performance, this reinvestment of explicit knowledge causes a regression to a level of processing associated with an earlier stage of learning (Lee & Swinnen, 1993). Such focus on the process of skill execution disrupts automatic processes that should be taking place if the individual is an expert. These automatic processes have been developed through practice and prevent the subcomponents of complex skills from overloading the limited capacity of the information processing system (Hasher & Zacks, 1979). As an individual progresses from novice to expert, he or she keeps less explicit knowledge in working memory and relies more upon implicit processes for skill execution. As a result, the expert becomes less able to invest explicit knowledge under conditions of pressure or distraction when compared with the novice.

Implicit motor learning strategies are designed to allow novice performers to bypass the accumulation of declarative knowledge that would normally occur early in learning while still gaining procedural knowledge about how to perform the task. This notion of avoiding a reliance on declarative knowledge parallels what occurs as expertise is achieved. Essentially, implicit learning strategies are attempting to get novice performers to "think" like experts as quickly as possible in the early stages of learning. However, the various methods of inducing implicit learning in sports tasks have been quite diverse in their approaches, especially with regards to attentional loading. The dual-task paradigm creates a situation in which participants' overall attentional capacity is largely consumed and the majority of attention is devoted to the secondary task, thus leaving the participant little opportunity to accumulate declarative knowledge about the primary task. Errorless and errorful protocols, which modify task difficulty in the early and later stages of learning, would have different levels of attentional loading because tasks that are more challenging and require more hypothesis-testing should have higher attentional demand (Kahneman, 1973). Finally, analogy learners and traditional explicit learners are presented with an uneven number of statements about proper technique that will lead to successful performance, thus creating the potential for an unbalanced attentional load. Previous authors discuss the benefits of implicit learning in terms of decreased declarative knowledge and a decreased dependency on working memory (see Masters & Poolton, 2012, for a review). However, previous authors largely fail to compare these differences and discuss the potential impact of implicit and explicit protocols on attentional demand. Such considerations seem logical since both the declarative knowledge acquired and the corresponding information in working memory are influenced by where the learner directs his or her attention.

The benefits of analogy learning are often seen in comparison to explicit learners, who suffer a performance decrement when transferred to conditions involving physiological stress, increased pressure, or an additional attentional load. If participants in an explicit condition are overloaded with instructional information during acquisition, they may prioritize learning the declarative knowledge associated with the rules rather than learning to execute the motor skill. In practical terms, it may be beneficial to utilize an explicit instructional approach that is reduced in quantity or overall length by prioritizing a critical component of the movement and asking participants to focus their attention on successful execution of this component. For example, in Poolton, Masters, and Maxwell (2006), explicit participants were given six rules to learn about a table tennis topspin forehand. In order to successfully execute the shot, the rule that states, "Move your playing arm forwards and upwards" could be considered more critical to performance than the rule that states, "Keep your feet a little wider than shoulder width apart." For a novice who is performing a complex movement, a reduction in the number of instructions and thus a simplification of attentional cues would seem preferential to having too many instructions and one's attention dispersed in many directions. In addition, this prioritized, reduced instruction approach would better reflect the way in which coaches teach learners how to perform a new skill.

Reinvestment Theory and The Constrained Action Hypothesis

The benefits of implicit motor learning strategies are often explained via Reinvestment Theory (Masters & Maxwell, 2008), which suggests that motor processes that are automated can be disrupted if they are run consciously using task-relevant, declarative knowledge to control movement mechanics. This reasoning is consistent with the Constrained Action Hypothesis, which suggests that a focus on movement control and production (typically induced by an internal focus of attention) can constrain or interfere with automatic processes that would normally regulate the movement and lead to a performance decrement, while a focus on movement effects (typically induced by an external focus of attention) encourages unconscious (i.e., automatic) processes that can lead to a performance benefit (Wulf, McNevin, & Shea, 2001; Wulf, 2007). Although the sources of a performance decrement are different (task-relevant declarative knowledge versus an internal focus of attention), both of these theories describe ways in which instruction can either facilitate or disrupt automatic processes that would normally allow the motor system to naturally self-organize.

Authors such as Komar and colleagues (2013) and Poolton and Zachry (2007) consider the impact of wording on implicit and explicit instructional approaches with regards to inducing an internal or an external focus of attention. An examination of analogy instructions used in previous literature illustrates that the resulting focus of attention is often external: "imagine moving the (table tennis) paddle up the hypotenuse of a right triangle" (Liao & Masters, 2001), "move the (table tennis) bat as if traveling up the side of a mountain" (Poolton, Masters, & Maxwell, 2006), "shoot as if you are trying to put cookies into a cookie jar on a high shelf" (Lam, Maxwell, & Masters, 2009) or "swing the (golf) club like a pendulum" (Poolton, Masters, & Maxwell, 2006). In contrast, the explicit instructions used in the aforementioned studies often involve asking the participant to monitor the position of hands, arms, feet, or body weight, thus leading to an internal focus of attention. This distinction is important because it could be an alternative explanation for differences found in previous literature between analogy and explicit groups.

Conclusions

Overall, research on the benefits of implicitly learning a complex motor skill has been limited to testing under psychological stress in the form of distraction (e.g., Masters, 1992), increased pressure (Maxwell et al., 2001), or decision-making (Masters et al., 2008). As Reber (1992) argued and Poolton, Masters, & Maxwell (2007) discussed, implicit processes should be more resilient than explicit processes to factors such as disruption, skill level, age, and IQ. While the relationship between implicit learning and disruption has been examined extensively in motor learning literature, other variables such as skill level, age, and IQ have not been considered. For example, Reber, Walkenfeld, & Hernstadt (1991) have demonstrated evidence for a correlation between explicit learning and IQ and a lack of correlation between implicit learning and IQ. Such a relationship has not been examined in motor learning literature. Additionally, the effects of physiological fatigue have only been examined in the form of a double Wingate protocol (Poolton, Masters, & Maxwell, 2007) and a VO_2 max treadmill test (Masters, Poolton, & Maxwell, 2008) with a rugby pass. Other forms of physiological stress or tasks should be examined to extend this line of research.

An overarching issue with implicit and explicit research concerns the question of accurately and completely assessing a learner's task-relevant knowledge. Since implicit knowledge, by definition, cannot be articulated, researchers are forced to rely on measures of explicit knowledge, which are often rudimentary. In several studies such as Masters (1992), Hardy, Mullen, and Jones (1996), and Liao and Masters (2001), verbal report protocols are used to assess declarative knowledge. As Shanks and St. John (1994) described, a dissociation between performance and verbalizable knowledge does not necessarily indicate the presence of implicit knowledge. Questions of verbal knowledge must be focused on information that is directly relevant to the task and also be sensitive enough to elicit responses that are accurate and sufficient.

With regards to dual-task implicit literature, alternative explanations relating to the task demands have been examined as a result of having participants perform under unequal cognitive loads during acquisition and transfer. With regards to errorless and errorful learning literature, alternative explanations related to psychological ramifications of the task protocol have been explored. However, alternative explanations of the results of analogy learning literature have not been previously examined. The purpose of this study was to compare the effects of analogy instruction on the performance and learning of a motor skill to those of explicit instruction consisting of a single statement (i.e., an equivalent amount of instruction). A secondary purpose was to compare analogy and reduced-rule explicit instruction to the traditional explicit instruction that included six rules (Poolton, Masters, & Maxwell, 2005).

CHAPTER 3

Method

Participants

Participants were 48 novice golfers (15 males and 33 females), ranging from 19 to 35 years of age (*M* = 24.29 yr, *SD* = 3.96 yr) who were recruited from the graduate and undergraduate population at a university in the southeastern United States. Novice status was defined as having no official golf handicap or prior formal golf putting experience (Cooke, Kavussanu, McIntyre, & Ring, 2010; Vine, Moore, Cooke, Ring, & Wilson, 2013). Miniature golf experience was not considered formal experience unless the participant indicated deliberate and systematic efforts to improve performance. All participants were right-handed. Left-handed persons were excluded from the study due to equipment constraints. In addition, non-native English speakers were excluded from the study due to the English letter generation task in the dual-task transfer condition.

Task and Apparatus

Figure 1 shows the apparatus. Participants putted on a SKLZ Vari-Break putting surface (SKLZ, Carlsbad, CA). The task during acquisition and the retention tests required participants to putt from the center starting point (indicated by the location of the ball in the figure) to a cup located ten feet away. This distance was selected based on previous research (Vine et al., 2013) and the results of a pilot study. The putting surface was placed on an elevated wooden platform so that the ball would drop into the cup at the conclusion of a successful putt. The task goal was to putt each ball so that it came to rest in the hole. Performance data included the number of *made putts* and the *x*- and *y*-dimension distance from the center of the cup for misses that remained in the viewable area for the camera used to record data. The number of putts that came to rest outside the viewing area (OVA putts) was also counted. To allow for long putts, a second putting surface was placed on the platform just beyond the cup. Participants used an Odyssey standard blade putter (36") and Titleist ProV1 golf balls. For the first transfer test, a sloped surface requiring a *breaking putt* was created by inserting a foam wedge (included with the putting surface) under the right side of the putting surface, centered with the middle row of dots and inserted two inches from the edge . For the second transfer test, participants completed a secondary random letter generation task while putting on the flat surface.

Figure 1. *The putting platform with the SKLZ Vari-Break putting surface and the overhead viewing area of the camera.*

Procedure

Upon arriving at the laboratory, participants read and signed an informed consent statement approved by the university's Institutional Review Board, indicating their voluntary participation in the study (see Appendix A). Demographic information that included age, handedness, and previous golf experience was collected. All participants confirmed that they had no prior experience with the task and that they were right-handed. Participants were informed that they would be asked to generate random English letters in response to an auditory cue during the experiment and verbally confirmed that they could perform this task. Each participant was quasi-randomly assigned to the Analogy Instruction (AI), Traditional Explicit Instruction (TEI), One-Rule Explicit Instruction (OREI), and Control (CTRL) groups such that group sizes were equal ($n = 12$). Table 1 outlines the experimental protocol.

Table 1. *Summary of the experimental protocol.*

Day	Phase	Activity
1	Acquisition	Informed consent Demographic information collected 150 practice trials from 10 feet
2	Acquisition	150 practice trials from 10 feet
3	Testing	Retention 1 (20 trials)—Conscious Motor Processing Subscale Transfer 1 (20 trials)—Conscious Motor Processing Subscale Transfer 2 (20 trials)—Conscious Motor Processing Subscale Retention 2 (20 trials)—Conscious Motor Processing Subscale Explicit rule recall and questionnaire at the conclusion of the study

Acquisition. The Acquisition phase took place over the course of two days. During the first day, participants were provided the instructions appropriate for their group assignment. The explicit instructions were taken from Poolton, Masters, and Maxwell (2005) and are listed below:

1. Keep your feet shoulder width apart and knees slightly bent.
2. Place your right-hand below your left when gripping the club handle.
3. Move the club back a short distance then swing the club forward with a smooth action along a straight line.
4. Allow the club to continue swinging a short distance after contact with the ball.
5. Adjust the speed of your movement so that the correct amount of force is applied.
6. When you hit the ball make sure that the putter head is at a right-angle to the direction you want the ball to travel (p. 367).

The TEI group was instructed to learn and use all six rules as they practiced putting. The OREI group was instructed to learn and use only Rule 3 since it encompassed the essential part of the putting stroke and was similar in length to the analogy instruction. The AI group was provided with the following passage describing how to putt:

> *Keep your body still like a grandfather clock and swing the putter in the same way that the clock pendulum operates.*

This analogy was based on that which was used in Vine et al. (2013) but was modified to reflect the recommendation of Poolton and Zachry (2007), who suggested that an external focus of attention (e.g., "swing the putter") be used in instruction rather than an internal focus of attention (e.g., "swing the arms"). The CTRL group was given no additional instruction beyond the goal of putting the ball into the cup.

Participants performed 15 trial blocks each consisting of 10 putts on both days (150 putts on Day 1 and 150 putts on Day 2). Figure 2 shows a person putting on the experimental platform. A one-minute rest period was provided after every two trial blocks. The number of trials (300) was chosen based on previous studies of analogy instruction (e.g., Masters et al., 2008; Poolton et al., 2006; Vine et al., 2013). The rest period was chosen based on participant feedback during pilot testing. At the conclusion of each rest period, participants were reminded of the appropriate instructions before beginning the next trial block. After each trial, the researcher recorded whether the putt was made or missed. For missed putts, a digital video camera (GR-DVL 9800, JVC, Wayne, NJ) suspended over the cup, captured an image of the ball's position, which was subsequently used to determine the *x*- and *y*-dimension distances from the center of the cup. The viewable area was centered on the cup and encompassed an area that consisted of the width of the carpet and approximately 100 cm in the short and long directions from the cup. Constant error (CE) in the *x*- and *y*-dimensions was measured using SiliconCoach motion analysis software (Siliconcoach Ltd, Dunedin, New Zealand). Balls that stopped outside of the camera area (OVA putts) were counted and recorded as being left, right, short, or long. Participants were able to view the surface of the green and thus receive inherent feedback about their performance.

No augmented feedback was provided. At the conclusion of each day, participants were instructed to abstain from putting practice or mental rehearsal of the task outside of the study setting.

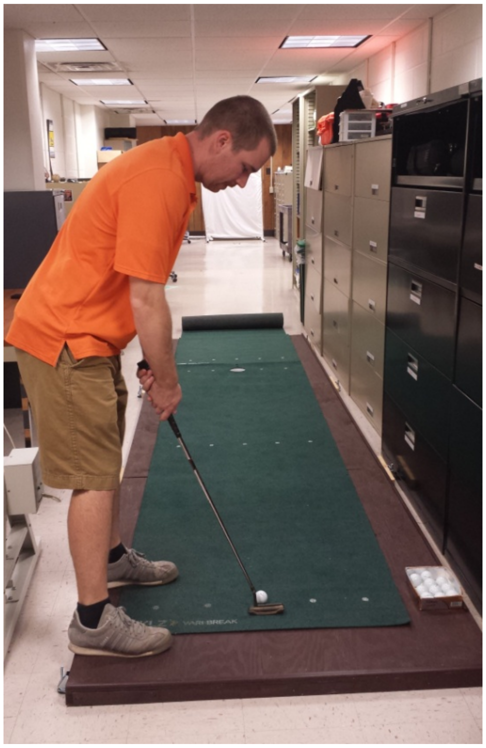

Figure 2. *A person putting on the experimental platform.*

Testing. The testing phase of the study consisted of two retention tests and two transfer tests (Retention 1, Transfer 1, Transfer 2, Retention 2). No instructions related to technique were presented to participants during testing. During Retention1and 2, participants performed under the same putting conditions as acquisition. During Transfer 1, participants performed under more challenging conditions by performing a breaking putt rather than a straight putt. During Transfer 2, participants performed under dual-task conditions to assess performance under increased attentional loading. The secondary task consisted of Baddeley's (1966) random letter generation task, which has been used in previous implicit learning research (Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007). The researcher played an audio file via a laptop that featured a tone at a rate of every 3 seconds and participants responded to each tone by speaking English consonants aloud in a random sequence. Vowels were excluded from the sequence in order to prevent participants from adopting simplifying strategies such as spelling words one letter at a time (Wareing, Fisk, & Murphy, 2000). Participants were instructed to avoid repeating a letter sequence, producing alphabetical sequences, and speaking each consonant with the same frequency. Just prior to the administration of Transfer 2, 20 baseline trials of the letter generation task were completed. Responses were recorded via an Olympus WS-400S digital voice recorder (Olympus Corporation of the Americas, Center Valley, PA) and subsequently transferred to a computer as audio files. If the participant generated letters that did not appear to be at random (e.g., alphabetical sequence, repeated letter, or the spelling of a word), the experimenter halted the primary task and reminded participants of the requirements of the secondary task. A lack of response prior to the subsequent tone or a vowel response was considered an error.

Retention 2 was administered at the end of the testing phase to test the contention that implicit learning strategies are more resilient and stable over time than those related to explicit learning (Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007). Accordingly, any benefit for analogy learning condition might become evident or more pronounced during a second retention test occurring after the disruptive experiences presented by transfer testing. Each test consisted of two 10-trial blocks. As during acquisition, participants rested for one minute after each trial block. They were not, however, reminded of any instructions.

At the conclusion of the each test, participants answered six questions from the Conscious Motor Processing Subscale of the Movement Specific Reinvestment Scale (MSRS) (Orrell, Masters, & Eves, 2009). The questions were modified for putting as in Vine and colleagues (2013) (see Appendix C). At the conclusion of testing, participants described in writing all of the movements, methods, and techniques they remembered using to perform the task (see Appendix D for full text of prompt). This prompt has been used in previous research to identify the explicit rules acquired during practice (Hardy et al., 1996; Liao & Masters, 2001; Masters, 1992; Mullen, Hardy, & Oldham, 2007).

Data Treatment and Analysis

Putting performance. The primary measure of putting performance was the number of putts made (Cooke et al., 2010; Mullen & Hardy, 2000; Vine et al., 2013). Secondary measures of putting performance included *x*- and *y*-dimension CE, ACE, and VE, and RE calculated for missed putts that remained in the camera viewing area (based on distances from the center of the cup to the center of the ball). Table 2 displays the formulas used to calculate each error measure. Additionally, the number of putts outside of the camera viewing area (OVA putts) was recorded.

Table 2. *The formulas used to calculate measures of error (Schmidt & Lee, 2011).*

Error Measure	Formula
Constant Error (CE)	$\Sigma (x_i - T)/N$, where x represents the trial, T is the target, and N is the number of trials
Absolute Constant Error (ACE)	$|\Sigma (x_i - T)/N|$, where x represents the trial, T is the target, and N is the number of trials
Variable Error (VE)	$\surd (\Sigma (x_i - M)^2/N)$, where x represents the trial, M is the mean constant error, and N is the number of trials
Radial Error (RE)	$\surd (\Sigma (x_i - T)^2/N)$, where x represents the trial, T represents the target, and N is the number of trials

The number of putts made during acquisition and each test were analyzed using separate chi-square tests. RE and *x*- and *y*-dimension CE, ACE, and VE were averaged across 20-trials to create 15 acquisition blocks and one block each for the retention and transfer tests. For acquisition, error measures were examined using separate 4 (group) x 15 (block) analyses of variance (ANOVA) with repeated-measures the last factor. For retention and transfer, error measures were examined using separate 4 (group) x 4 (test) ANOVAs with repeated measures on the last factor. All significant interactions and main effects were followed up using Sidak procedures. If the assumption of sphericity was violated, *F*-values were reported using the Greenhouse-Geisser degrees of freedom correction. In such cases, original degrees of freedom were reported. Finally, the number of OVA putts was examined using separate chi-square tests for acquisition and each test. Alpha was set at .05 for all statistical tests.

Secondary task performance. Secondary task performance for Transfer 2 was analyzed to identify potential group differences by examining the number of errors committed and the randomness of the letters generated. Percent redundancy, an indicator of randomness, was calculated for both single-task and dual-task conditions using the procedure set forth in Baddeley (1966). Measures of randomness are problematic, however, because randomness is easier disproved than proved and varies according to the specific criterion against which it is judged (Wagenaar, 1972). When only the frequencies of single responses are considered, an analysis of randomness assesses what is known as the first order of redundancy. A sequence of letters contains the maximum first-order information when each letter is used with equal frequency. Information may be defined as that which removes or reduces uncertainty (Attneave, 1959). The binary digit, or bit, is the unit most often used in the measurement of information and uncertainty. The value *H* represents the amount of uncertainty or information, expressed in bits.

As the usage of individual letters becomes unbalanced, the sequence becomes more redundant. For the current study, the number of errors (i.e., failure to respond to the tone or responding with a vowel) was totaled for each participant. The difference between the number of trials and the number of errors was then calculated to determine the valid number of cases. For all valid cases, the frequency of usage for each consonant was totaled and an *H*-value was calculated for each participant (Attneave, 1959). The formula for *H*, where n is the number of responses in the sample, and n_i (i = 1, 2, … 21) is the frequency with which the *i*th letter of the alphabet, is as follows:

$$H = \log_2 n - \frac{\sum \; n_i \times \log_2 n_i}{n}$$

Due to the size of the sample (i.e., the number of letters generated), the Miller-Madow correction was used on all *H*-values (Miller, 1955). This information score was then converted into percent redundancy as a measure of secondary task performance (Attneave, 1959). A paired-samples t-test was used to assess differences in redundancy scores between the baseline and dual-task condition, and two separate univariate ANOVAs were used to assess group differences for baseline and the dual-task condition. Significant main effects were followed up with Sidak procedures. The error totals for each group during secondary task performance were also analyzed using a chi-square test. Alpha was set at .05 for all statistical tests.

Conscious motor processing. Each of the six items on the Conscious Motor Processing Subscale of the MSRS (see Appendix C) was scored on a 5-point Likert scale with anchors of 1 (never), 3 (sometimes), and 5 (always). Each participant received a mean score for all six items, which was then used for subsequent analysis. Scores were examined using a 4 (group) x 4 (test) ANOVA with repeated-measures on the last factor. All significant interactions and main effects were followed up using Sidak procedures. If the assumption of sphericity was violated, *F*-values were reported using the Greenhouse-Geisser degrees of freedom correction. Alpha was set at .05 for all statistical tests.

Explicit rules. Each participant's written responses to the prompt to describe the movements, methods, and techniques used to perform the task (see Appendix D) were examined to identify explicit rules related to task performance. Explicit rules consisted of statements relating to the movements associated with putting or hypothesis-testing. Movement-related statements included reference to instructions or mechanical and procedural aspects of the task (e.g., "I kept my knees bent" or "I placed the ball in line with the inside of my left ankle"). Hypothesis-testing included statements in which the participant noted using an outcome to guide subsequent trials (e.g., "I tried swinging the club at different speeds"). These statement categories were considered to represent the entirety of explicit task-relevant knowledge. Redundant statements were only counted once. Statements were deemed to be redundant if they did not contribute novel information regarding mechanics, technique, or hypothesis-testing procedures.

Two independent raters who were blind to the purpose of the study and the associated group assignment each identified and counted the number of rules generated for every participant. Each rater was provided with the aforementioned examples of rules that constituted relevant and irrelevant information. An intra-class correlation was used to assess inter-rater reliability, with an acceptable inter-rater reliability set at 0.75 or higher (Gwet, 2012). For analysis purposes, each participant was scored using the average score of the two raters. The total number of rules generated by each group was examined using a chi-square analysis. The number of other statements, such as those related to environmental observations or feelings, were also examined using a chi-square analysis. Alpha was set at .05 for both tests.

CHAPTER 4

Results

Results presented in this chapter are divided into the acquisition and testing phases of the study. For each phase, performance data included the number of putts made, error measures, and the number of OVA putts. For the testing phase, secondary task performance during Transfer 2 is also reported. as are the responses to the Conscious Motor Processing Subscale of the MSRS administered after each test and the number of explicit rules listed at the end of the study.

Putting Performance during Acquisition

Made putts. The total number of made putts for each group during acquisition is displayed in Table 3 and the average number of made putts for each group throughout the study is displayed in Figure 3. The chi-square analysis revealed that the observed counts differed significantly from expected, χ^2 (3, n = 7487) = 59.44, $p < .001$. During acquisition, the OREI group made the most putts (2077) while the control group made the fewest (1645). These counts represented 58% and 46%, respectively, of the total number of possible putts (3,600) for each group. The significant chi-square value was due to the lower than expected number of made putts for the CTRL group and the higher than expected number of made putts for the OREI and AI groups.

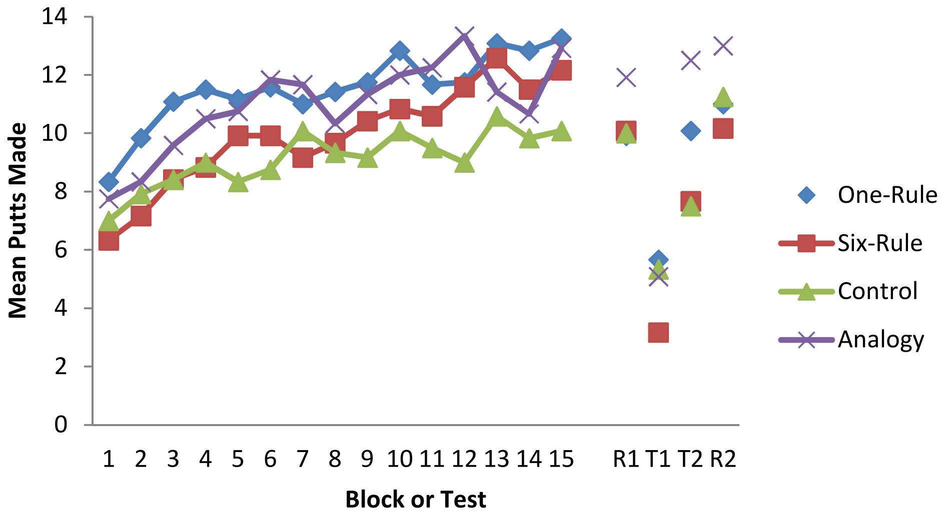

Figure 3. *The mean number of putts made by group across acquisition and testing.*

Table 3. *Observed, expected, and chi-square residual values for each group for the total number of made putts during acquisition.*

Group	Observed	Expected	Residual
OREI	2077	1871.8	205.3
TEI	1789	1871.8	-82.8
CTRL	1645	1871.8	-226.8
AI	1976	1871.8	104.3

Error Measures. CE, ACE, and VE measures were calculated for both the *x*- and *y*-dimensions, and RE was calculated as a composite score of these two dimensions. For *x*-dimension CE, the four groups performed similarly during acquisition ($M = 3.08$; $SD = .56$). All groups did, however, show improved accuracy across trial blocks. These observations were supported by the significant main effect for block, $F\ (14, 616) = 1.98$, $p = .042$, partial $\eta^2 = .043$. Neither the main effect for group, $F\ (3, 44) = .93$, $p = .435$, nor the Group × Block interaction, $F\ (42, 616) = 1.27$, $p = .173$, were significant. Post hoc procedures following the significant block effect revealed no significant differences between blocks ($p > .05$). For *y*-Dimension CE, the four groups performed similarly during acquisition (*M* = 26.41; *SD* = 1.40). There were no significant effects for the Group × Block interaction, F (42, 616) = .951, $p = .542$, the main effect of group, F (14, 616) = 1.07, $p = .385$, or the main effect of Block, F (14, 616) = 1.07, $p = .385$.

For *x*-dimension ACE, there was a group main effect, F (3, 44) = 3.21, $p = .032$, partial $\eta^2 = .180$. Post hoc procedures revealed that four groups performed similarly across acquisition (*M* = 7.91; *SD* = .38). Neither the Group × Block interaction, F (42, 616) = 1.41, $p = .084$, nor the main effect of block, F (14, 616) = 1.36, $p = .198$, were significant. For *y*-dimension ACE, there was a main effect for group, F (3, 44) = 3.52, $p = .023$, partial $\eta^2 = .194$. Post hoc procedures revealed a significant difference between the TEI group (*M* = 34.16; *SD* = 2.35) and AI group (*M* = 24.80; *SD* = 2.35), $p = .043$. Neither the Group × Block interaction , F (42, 616) = 1.06, $p = .38$, nor the main effect of Block, F (14, 616) = .89, $p = .538$, were significant.

For *x*-dimension VE, the four groups performed similarly during acquisition (*M* = 14.04; *SD* = .66). There were no significant effects for the Group × Block interaction, F (42, 616) = 1.12, $p = .351$, main effect for group, F (3, 44) = .73, $p = .542$, or main effect for Block, F (14, 616) = .63, $p = .606$. For *y*-Dimension VE, there was a main effect for group, F (3, 44) = 4.65, $p = .007$, partial $\eta^2 = .241$. Post hoc procedures revealed a significant difference between the OREI group (*M* = 28.99; *SD* = 1.96) and TEI group (*M* = 39.02; *SD* = 1.96), $p = .005$. Neither the Group × Block interaction, F (42, 616) = 1.03, $p = .409$, nor main effect for Block,. F (14, 616) = 1.29, $p = .279$, were significant.

For RE, there was a main effect for group, F (3, 44) = 3.34, $p = .028$, partial $\eta^2 = .185$. Post hoc procedures revealed that the four groups performed similarly during acquisition (*M* =

48.09; *SD* = 1.11). Neither the Group × Block interaction, *F* (42, 616) = 1.06, *p* = .386, nor the main effect of Block, *F* (14, 616) = .48, *p* = .889, were significant.

OVA Putts. The missed putts that came to rest outside of the camera's viewing area consisted of those that went off the surface (i.e., left, right, or long) or those that were too short of the cup to be captured by the camera. Table 4 shows the number of OVA putts that were left, right, short, or long for each group, and Table 5 shows Observed, expected, and chi-square residual values for each group for the OVA putts. During acquisition, a total of 1,999 putts (13.9%) came to rest outside the viewing area with the majority (1,488) of these putts going long. The AI group had the fewest OVA putts (11% of total putts hit) while the TEI group had the highest number of OVA putts (17% of total putts hit). The chi-square analysis on the total number of OVA putts during acquisition revealed that the observed number differed significantly from expected, χ^2 (3, *n* = 1999) = 94.04, *p* < .001. This difference was due to the higher than expected number of made putts for the TEI group and the lower than expected number the AI group.

Table 4. *The number of OVA putts for each group during acquisition.*

Group	Left	Right	Short	Long	Totals
OREI	29	49	14	312	404
TEI	40	94	9	483	626
CTRL	35	90	10	453	588
AI	24	98	19	240	381
Totals	128	331	52	1488	1999

Table 5. *Observed, expected, and chi-square residual values for each group for the total number of OVA putts during acquisition.*

Group	Observed	Expected	Residual
OREI	404	499.8	-95.8
TEI	626	499.8	126.3
CTRL	588	499.8	88.3
AI	381	499.8	-118.8

Putting Performance during Testing

Made Putts. Table 6 shows the total number of made putts for each group during Retention 1. The AI group made the most putts (59.6%) during Retention 1 while the OREI group made the least (50%). The chi-square analysis, however, was not significant, χ^2 (3, *n* = 503) = 3.17, *p* = .366.

Table 6. *Observed, expected, and chi-square residual values for each group for the total number of made putts during Retention 1*

Group	Observed	Expected	Residual
OREI	119	125.8	-6.8
TEI	121	125.8	-4.8
CTRL	120	125.8	-5.8
AI	143	125.8	17.3

Table 7 shows the total number of made putts for each group during Transfer 1. The OREI group made the most putts (28%) while the TEI group made the fewest puts (16%). The chi-square analysis revealed that the observed number of made putts differed significantly from expected, χ^2 (3, *n* = 231) = 9.43, *p* = .024. The source of this difference was the lower than expected number of made putts for the TEI group.

Table 7. *Observed, expected, and chi-square residual values for each group for the total number of made putts during Transfer 1.*

Group	Observed	Expected	Residual
OREI	68	57.8	10.3
TEI	38	57.8	-19.8
CTRL	64	57.8	6.3
AI	61	57.8	3.3

Table 8 shows the total number of made putts for each group during Transfer 2. During Transfer 2, the AI group made the most putts out of the four groups (63%) while the CTRL group made the fewest putts (38%). The chi-square analysis revealed that the number of made putts differed significantly from expected, χ^2 (3, $n = 453$) = 21.22, $p < .001$. This difference was due to the lower than expected number of made putts for the TEI and CTRL groups and the higher than expected number of made putts for the AI group.

Table 8. *Observed, expected, and chi-square residual values for each group for the total number of made putts during Transfer 2.*

Group	Observed	Expected	Residual
OREI	121	113.3	7.8
TEI	92	113.3	-21.3
CTRL	90	113.3	-23.3
AI	150	113.3	36.8

Table 9 displays the total number of holed putts for each group during Retention 2. The AI group made the most putts (65%) while the TEI group made the fewest putts (51%). The chi-square analysis revealed that the total number of made putts did not differ significantly from expected, χ^2(3, $n = 545$) = 4.50, $p = .213$.

Table 9. *Observed, expected, and chi-square residual values for each group for the total number of made putts during Retention 2.*

Group	Observed	Expected	Residual
OREI	132	136.3	-4.3
TEI	122	136.3	-14.3
CTRL	135	136.3	-1.3
AI	156	136.3	19.8

Error Measures. For x-dimension CE, the four groups performed similarly during testing ($M = -.50$; $SD = .56$). There was a significant test main effect, $F\ (3, 132) = 19.06$, $p < .001$, partial $\eta^2 = .302$. Post hoc procedures revealed significant differences between Retention 1 ($M = 4.07$; $SD = 1.49$), and Transfer 1 ($M = -8.99$; $SD = 1.12$), $p < .001$, Transfer 1 and Transfer 2 ($M = 2.65$; $SD = 1.38$), $p < .001$, Transfer 1 and Retention 2 ($M = 2.07$; $SD = 1.25$), $p < .001$. Neither the Group × Test interaction, $F\ (9, 132) = 1.82$, $p = .070$, nor the main effect for group, $F\ (3, 44) = .017$, $p = .997$, was significant.

For y-Dimension CE, the four groups performed similarly during testing ($M = 30.39$; $SD = 1.72$). There was a significant test main effect, $F\ (3, 132) = 4.98$, $p = .005$, partial $\eta^2 = .102$. Post hoc procedures revealed significant differences between Retention 1 ($M = 34.22$; $SD = 2.79$) and Retention 2 ($M = 22.12$; $SD = 2.98$), $p = .038$, along with Transfer 1 ($M = 37.33$; $SD = 2.71$) and Retention 2, $p = .007$. Neither the Group × Test interaction, $F\ (9, 132) = 1.04$, $p = .409$, nor the group main effect, $F\ (3, 132) = 19.06$, $p < .001$, was significant.

For x-Dimension ACE, the four groups performed similarly during testing ($M = 8.08$; $SD = .50$). There was a significant test main effect, $F\ (3, 132) = 2.79$, $p = .043$, partial $\eta^2 = .060$. Follow-up comparisons revealed significant differences between Transfer 1 ($M = 10.48$; $SD =$

.85) and Retention 2 (*M* = 6.99; *SD* = .81), *p* = .040. Neither the Group × Test interaction, *F* (9, 132) = .84, *p* = .582, nor the main effect for group, *F* (3, 44) = .89, *p* = .452, were significant.

For *y*-Dimension ACE, the four groups performed similarly during acquisition (*M* = 31.93; *SD* = 1.55). There was a significant Test main effect, *F* (3, 132) = 4.63, $p < .004$, partial $\eta^2 = .095$. Post hoc procedures revealed significant differences between Retention 1 (*M* = 35.25; *SD* = 2.55) and Retention 2 (*M* = 24.04; *SD* = 2.61), *p* = .022, and Transfer 1 (*M* = 37.33; *SD* = 2.71) and Retention 2, *p* = .016. Neither the Group × Test interaction, *F* (9, 132) = 1.05, *p* = .406, nor the main effect for group, *F* (3, 44) = 1.65, *p* = .191, were significant.

For *x*-Dimension VE, the four groups performed similarly during testing (*M* = 14.02; *SD* = .73). The Group × Test interaction, *F* (9, 132) = .549, *p* = .685, group main effect, *F* (3, 44) = .41, *p* = .743, and test main effect, *F* (3, 132) = .309, *p* = .626, were not significant. For *y*-Dimension VE, there was a significant group main effect, *F* (3, 44) = 3.75, $p < .018$, partial $\eta^2 = .204$. Post hoc procedures indicated that there were significant differences between the OREI group (*M* = 27.93; *SD* = 2.44) and the TEI group (*M* = 38.85; *SD* = 2.44), *p* = .017. There was also a significant test main effect, *F* (3, 132) = 8.34, $p < .001$, partial $\eta^2 = .159$. Post hoc procedures revealed significant differences between Retention 1 (*M* = 30.79; *SD* = 1.57) and Retention 2 (*M* = 35.23; *SD* = 1.28), *p* = .013, and Transfer 2 (*M* = 30.71; *SD* = 1.57) and Retention 2, *p* = .017. The Group × Test interaction was not significant, *F* (9, 132) = 1.92, *p* = .125.

For radial error, the four groups performed similarly during testing (*M* = 48.59; *SD* = 1.12). There was a significant test main effect, *F* (3, 132) = 7.20, $p < .001$, partial $\eta^2 = .141$. Post hoc procedures revealed significant differences between Retention 1 (*M* = 52.34; *SD* = 10.74) and Retention 2 (*M* = 40.76; *SD* = 9.77), *p* = .001, and Transfer 1 (*M* = 52.95; *SD* = 9.42) and

Retention 2, *p* = .001. Neither the Group × Test interaction,, *F* (9, 132) = .99, *p* = .452, nor the main effect for group were significant, *F* (3, 44) = 1.94, *p* = .137.

OVA Putts. Of the 3,840 total putts hit during testing, 694 (18%) were OVA. During Retention 1, the AI group had the fewest number of OVA putts while the CTRL group had the highest number of OVA putts. The observed counts differed significantly from those expected, χ^2 (3, *n* = 138) = 9.13, *p* = .028. These differences were likely due to the lower-than-expected number of OVA putts for the AI group and the higher-than-expected number for the CTRL group. Table 10 shows the observed, expected, and chi-square residual values for each group for the total number of OVA putts during Retention 1.

Table 10. *Observed, expected, and chi-square residual values for each group for the total number of OVA putts during Retention 1.*

Group	Observed	Expected	Residual
OREI	30	34.5	-4.5
TEI	36	34.5	1.5
CTRL	48	34.5	13.5
AI	24	34.5	-10.5

During Transfer 1, the OREI and AI groups tied for the fewest OVA putts while the TEI group had the most. These observed counts differed significantly from those expected, χ^2 (3, *n* = 249) = 34.90, *p* < .001. These differences were likely due to the higher than expected number of OVA putts for the TEI group. Table 11 shows the observed, expected, and chi-square residual values for each group for the total number of OVA putts during Transfer 1.

Table 11. *Observed, expected, and chi-square residual values for each group for the total number of OVA putts during Transfer 1.*

Group	Observed	Expected	Residual
OREI	44	62.3	-18.3
TEI	101	62.3	38.8
CTRL	60	62.3	-2.3
AI	44	62.3	-18.3

During Transfer 2, the AI group had the fewest OVA putts while the TEI and CTRL groups tied for the most. These observed counts differed significantly than those expected, χ^2 (3, n = 203) = 37.26, $p < .001$. These differences were likely due to the lower than expected number of OVA putts for the AI group and the higher than expected numbers for the TEI and CTRL groups. Table 12 shows the observed, expected, and chi-square residual values for each group for the total number of OVA putts during Transfer 2.

Table 12. *Observed, expected, and chi-square residual values for each group for the total number of OVA putts during Transfer 2.*

Group	Observed	Expected	Residual
OREI	36	50.8	-14.8
TEI	72	50.8	21.3
CTRL	72	50.8	21.3
AI	23	50.8	-27.8

During Retention 2, the AI group had the fewest OVA putts while the CTRL group had the most OVA putts. These observed counts did not differ significantly from those expected, χ^2(3, n = 103) = 7.25, $p = .064$.. Table 13 shows the observed, expected, and chi-square residual values for each group for the total number of OVA putts during Retention 2. Table 14 shows the number of

OVA putts for each group during testing, and Table 15 shows the number of OVA putts that missed in each direction.

Table 13. *Observed, expected, and chi-square residual values for each group for the total number of OVA putts during Transfer 2.*

Group	Observed	Expected	Residual
OREI	22	25.8	-3.8
TEI	25	25.8	-.8
CTRL	37	25.8	11.3
AI	19	25.8	-6.8

Table 14. *The frequency of OVA putts by group during testing.*

	OREI	TEI	CTRL	AI	Totals
Retention 1	30	36	48	24	139
Transfer 1	44	101	60	44	249
Transfer 2	36	72	72	23	203
Retention 2	22	25	37	19	103
Totals	132	234	217	110	694

Table 15. *The directional frequency of OVA putts by test.*

	Left	Right	Short	Long	Totals
Retention 1	4	31	1	103	139
Transfer 1	17	14	1	217	249
Transfer 2	20	19	1	163	203
Retention 2	4	15	0	84	103
Totals	45	79	3	567	694

Secondary Task Performance

During Transfer 2, *H*-values (information per letter in bits) were calculated and converted into percent redundancy scores to examine the redundancy of the letters generated under both single-task and dual-task conditions (Attneave, 1959; Baddeley, 1966; Miller, 1955). Each participant completed 20 baseline trials, but the number of dual-task trials varied according to the pace of putting (*M* = 63.25, *SD* = 11.94). The mean number of valid baseline trials was 18.65 while the mean number of valid dual-task trials was 61.73. Figure 5 shows the percent redundancy scores of each group for baseline and dual-task conditions. The redundancy of responses changed significantly between the two conditions, t(47) = 28.59, *p* < .001, with values decreasing from baseline (*M* = .33, *SD* = .05) to dual-task conditions (*M* = .14, *SD* = .04). Two separate univariate ANOVAs revealed that there were no significant differences in percent redundancy between groups at baseline, *F* (3, 44) = 2.07, *p* = .118, and no significant differences in percent redundancy between groups during the dual-task condition, *F* (3, 44) = 1.48, *p* = .234.

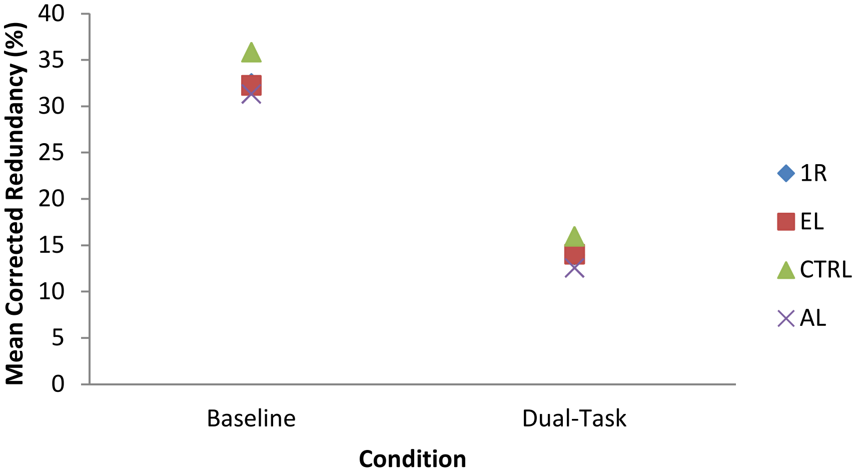

Figure 4. *Mean corrected redundancy scores of each group during baseline and the dual-task condition.*

Table 16 shows the number of letter-generation errors committed during baseline and dual-task conditions. The total number of letter-generation errors was similar during baseline (65) and the dual-task condition (73). Separate chi-square tests were performed to compare the number of errors with expected values during baseline and the dual-task conditions. The analysis was not significant for the baseline condition, χ^2 (3, *n* = 65) = .908, *p* = .824, but was for the dual-task condition, χ^2 (3, *n* = 73) = 42.56, *p* < .001. This difference was due to the higher than expected number of errors committed by the CTRL group. Table 17 shows the Observed, expected, and chi-square residual values for each group for the total number of secondary task errors during the Transfer 2 baseline condition, and Table 18 shows the Observed, expected, and chi-square residual values for each group for the total number of secondary task errors during the Transfer 2 dual-task condition.

Table 16. *The number of letter-generation errors committed during baseline and dual-task conditions.*

Group	Baseline	Dual-Task
OREI	17	10
TEI	15	14
CTRL	19	42
AI	14	7

Table 17. *Observed, expected, and chi-square residual values for each group for the total number of secondary task errors during the Transfer 2 baseline condition.*

Group	Observed	Expected	Residual
OREI	17	16.3	.8
TEI	15	16.3	-1.3
CTRL	19	16.3	2.8
AI	14	16.3	-2.3

Table 18. *Observed, expected, and chi-square residual values for each group for the total number of secondary task errors during the Transfer 2 dual-task condition.*

Group	Observed	Expected	Residual
OREI	10	18.3	-8.3
TEI	14	18.3	-4.3
CTRL	42	18.3	23.8
AI	7	18.3	-11.3

Conscious Motor Processing

Table 19 lists the mean score of each group on the Conscious Motor Processing Subscale of the MSRS administered after each test. The four groups performed similarly during testing (*M* = 3.42; *SD* = .05). There was a significant main effect for test, *F* (3, 132) = 186.61, $p < .001$, partial $\eta^2 = .809$. Post hoc procedures revealed significant differences in scores on Tests 1 (*M* = 3.78; *SD* = .45) and 2 (*M* = 4.26; *SD* = .45), $p < .001$, Tests 1 and 3 (*M* = 1.94; *SD* = .63), $p < .001$, Tests 2 and 3, $p <.001$, Tests 2 and 4 (*M* = 3.72; *SD* = .69), and Tests 3 and 4, $p < .001$. Neither the group × test interaction, *F* (7.48, 393.25) = .699, *p* = .682, nor the main effect for group, *F* (3, 44) = .32, *p* = .809, were significant.

Table 19. *The mean score of each group on the Conscious Motor Processing Subscale of the MSRS.*

	Retention 1	Transfer 1	Transfer 2	Retention 2	Group Mean
OREI	3.85	4.22	1.97	3.62	3.42
TEI	3.47	4.14	1.99	3.78	3.35
CTRL	3.83	4.36	1.93	3.74	3.47
AI	3.96	4.32	1.88	3.75	3.48
Test Mean	3.78	4.26	1.94	3.72	

Explicit Rules

The intra-class correlation between two independent raters was above the acceptable threshold of .75 (Gwet, 2012), ICC (2, 47) = .88, indicating sufficient inter-rater reliability. The chi-square analysis revealed no significant differences in the observed and expected frequency of total rules listed for each group, χ^2 (3, n = 230) = 5.10, p = .165, or the observed and expected frequency of total unrelated statements listed for each group, χ^2 (3, n = 75) = 3.67, p = .300. Table 20 lists the observed, expected, and chi-square residual values for each group for the total number of rules, and Table 21 lists the observed, expected, and chi-square residual values for each group for the total number unrelated statements.

Table 20. *Observed, expected, and chi-square residual values for each group for the total number of rules listed.*

Group	Observed	Expected	Residual
OREI	45	57.5	-12.5
TEI	68	57.5	10.5
CTRL	62	57.5	4.5
AI	55	57.5	-2.5

Table 21. *Observed, expected, and chi-square residual values for each group for the total number of unrelated statements listed..*

Group	Observed	Expected	Residual
OREI	21	18.8	2.3
TEI	12	18.8	-6.8
CTRL	23	18.8	4.3
AI	19	18.8	.3

CHAPTER 5

Discussion

The purpose of this study was to compare the effects of analogy instruction on the performance and learning of a motor skill to those of explicit instruction consisting of a single statement (i.e., an equivalent amount of instruction). A secondary purpose was to compare analogy and reduced-rule explicit instruction to a traditional explicit instruction comprised of six rule statements (Poolton, Masters, & Maxwell, 2005). Although previous research has compared analogy and traditional explicit instruction, the current study was unique in addressing the potential role of the amount of information contained in such instructions by also including a reduced-rule explicit instruction group. The results revealed that analogy and reduced-rule explicit instruction facilitated motor performance and learning compared to traditional explicit instruction (e.g., comprised of six rules) and no instruction. These findings were consistent with previous research showing benefits of using an analogy or implicit instruction approaches (Komar et al., 2014; Lam, Maxwell, & Masters, 2009; Law et al., 2003; Liao & Masters, 2001; Masters et al., 2008; Poolton et al., 2006; Vine et al., 2013).

The most important findings emerged from the retention and transfer tests. Although all four groups demonstrated similar performance during retention, differences were seen during transfer testing. When participants were transferred to the breaking putt condition (i.e., Transfer 1), performance decreased for all four groups relative to the other tests. Participants made the fewest putts during Transfer 1 (231 or 24%), indicating that the breaking putt posed the greatest performance challenge. The TEI group made the fewest putts during Transfer 1 (34% fewer than expected), indicating that traditional explicit instruction comprised of several rules compromises the capability to adapt to novel task demands. It is possible that the instruction to remember six rules constrained the attentional resources of the TEI group such that they were less able to cope with the more challenging task demands of the breaking putt. The AI group and the OREI groups were only asked to use a single statement that focused on the motion of the putter, which presumably facilitated their performance. The OREI and AI groups both made slightly more putts than expected (8% and 6%, respectively). The CTRL group also made more putts than expected (11%), suggesting that the conditions unique to the TEI group (e.g., using six rules) were detrimental to transfer. Neither the analogy nor reduced-rule explicit instruction conferred a transfer benefit compared to the control condition, which indicated that the pattern of results during Transfer 1 was due to the *disadvantage* conferred on the TEI group rather than any benefits for the AI & OREI groups. In other words, analogy and reduced-rule instruction did not facilitate learning as indicated by Transfer 1 performance compared to no instruction at all.

During Transfer 2, participants experienced an additional attentional load by performing under dual-task conditions. The results from this condition revealed that both analogy and reduced-rule instruction conferred a learning benefit, although to different extents. The AI group made substantially more putts than expected (32%) and the OREI group made slightly more (7%). In contrast, the TEI and CTRL groups made substantially fewer putts than expected (19% and 21%, respectively). These findings suggested that analogy instruction can facilitate transfer to conditions that require a relatively high degree of attentional control, which is particularly germane to the sport of golfing. The fact that the OREI group did not show similar performance to the AI group further suggests that the use of analogy instruction confers benefits beyond those attributable to the reduced attentional load of the instruction statement. The performance of all four groups viewed together indicated that reduced instruction did facilitate transfer compared to traditional explicit instruction and no instruction. It may be that the TEI group used a larger portion of their attentional capacity due to the instruction to remember and use six explicit rules. Although the performance results suggested that the AI group may have relied more heavily on implicit processing during performance compared to the OREI group, the lack of differences for conscious motor processing scale scores and number of rules generated were not consistent with this view. Thus, the results did not support previous suggestions that implicit learning via analogy instruction facilitates transfer to dual-task conditions. Nevertheless, the AI group did perform better than the other groups during Transfer 2, which has implications for motor skill instruction. Komar et al. (2014) and Masters and Liao (2003) suggest that it is this unique format that allows for the "chunking" of important information which reduces the load on working memory and efficiently conveys information about movement. Novices in particular often struggle as they process information from various sources during motor skill performance, and the use of analogy instruction may represent a viable way to facilitate the development of attentional control.

The lack of significant findings for either retention test is difficult to interpret. The total number of putts made during each test was similar to the numbers made during the latter portions of acquisition and greater than at the outset of training. These observations suggest that although participants did show at least some marginal gains in putting skill as a result of training, no evidence was found to suggest that any of the instructional approaches produced any motor learning effects compared to no instruction at all. It is also important to note that there were significant differences in the number of putts made during acquisition when compared with expected counts. The AI and OREI groups outperformed the TEI and CTRL groups during acquisition, indicating that analogy and reduced-rule explicit instruction imparted *performance effects* on putting rather than more permanent *learning effects*. Presumably, the instructions used in the AI and OREI groups may have freed attentional resources needed to perform the task (compared to the TEI and CTRL groups) during practice and ultimately helped learners learn the type of attentional control that resulted in the benefits seen during the dual-task condition of Transfer 2.

The results of the secondary performance measures produced evidence that was largely consistent with that seen in the primary measure. Interestingly, the AI group produced fewer OVA putts than expected during Retention 1 (30%) while the CTRL group produced more (39%). For the measurable missed putts, there was a group main effect during acquisition on measures of ACE and RE but no significant group differences in post hoc procedures. From a practical standpoint, this indicates that the AI group received more opportunities to evaluate their near misses using inherent feedback, and is consistent with the notion that analogy instruction facilitated the learning of some degree of control over putting (albeit only in terms of more consistently leaving putts within an arbitrarily defined measurement area). Otherwise, the other results from the secondary measures during acquisition and the other tests provided no additional qualification of the interpretation of the primary performance measure.

The directional frequency of OVA indicated that that participants tended to miss long (i.e., off of the putting platform) rather than to the left, right, or short. This type of miss may have been indicative of participants' desire to get the ball to the hole combined with a lack of speed control due to unfamiliarity with the task. With the exception of a few misses during Transfer 2, all OVA putts in the x-dimension were a result of the golf ball *lipping out* of the cup, meaning that it hit the cup on one of the edges with enough speed to propel it off the putting platform. In the current study, this result was treated as an artifact of using an actual cup for the putting task. The fact that *lipped out* putts accounted for nearly all of the x-dimension OVA putts, indicated that participants were generally able to keep the putter square to the target with the primary challenge on these putts being one of correctly selecting force (i.e., *y*-dimension error). Moreover, the error measures for the measurable missed putts also showed more pronounced results in the *y*-dimension. It may be the case that putting lends itself to an all-or-nothing approach in certain cases. Although putts that aimed to the left or right cannot enter the cup, those in line can be made as long as a minimum force has been applied (i.e., the amount sufficient to propel the ball all the point of dropping into the hole, but no further). Applying forces in excess of this value is not necessarily problematic as long as the ball is not hit so hard that it either rolls over or bounces out of the hole. Recognition of this fact coupled with the knowledge that the ball *must* at least reach the cup may incline performers to err in ways that do not result in an even distribution of missed putts around the hole. This problem is likely magnified by the fact that novices are still learning how to control the speed of their putts. A putting task incorporating a flat target would allow a more precise examination of directional errors and a larger putting surface (when feasible) would produce more measurable putts (i.e., fewer OVA putts).

Previous literature related to implicit and explicit motor learning has used secondary task loading in two ways. First, it has been used as a means to purportedly promote implicit learning (e.g., Hardy, Mullen & Jones, 1996; Masters, 1992). Second, it has been used as a means to test the capability to perform when transferred to a condition of increased attentional load (e.g., Liao & Masters, 2001; Poolton, Masters, & Maxwell, 2007). For testing, several variations have been used, including random letter generation (Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007), monitor low- and high-pitched tones (Maxwell et al., 2001; Poolton, Masters, & Maxwell, 2005), and counting backwards (Capio et al., 2011; Liao & Masters, 2001). These different procedures make comparing results across studies difficult. Although the focus has been on primary task performance, secondary task performance should be included in future research because these measures can provide insight into how various instructional approaches impact attentional during attentional loading conditions. The results of the current study revealed no group differences in secondary task performance for the three instruction groups. Compared to previous research, however, the instructions for the current study prioritized the golf putting task to a greater extent. Instructions to "be as accurate as possible on both tasks") (Poolton, Masters, & Maxwell, 2005) placed equal weight on the tasks and those halting the primary task can actually be viewed as prioritizing secondary task (Poolton, Masters, & Maxwell, 2007). These different procedures raise two important questions:

1. What portion of attentional resources should participants be devoting to the primary and secondary tasks during testing, as opposed to training?
2. How might instructions related to either the primary or secondary task influence performance?

The current study was intended to provide insight into instructional approaches that have been purported to promote either implicit or explicit learning. Although the results revealed that analogy instruction conferred a relatively large benefit on the number of putts made during testing under dual-task conditions and a smaller benefit for reduced-rule explicit instruction, there was no evidence supporting the notion that these effects resulted from different types of processing. The results for the Conscious Motor Processing Subscale of the MSRS revealed no group differences. According to Reinvestment Theory(Masters & Maxwell, 2008), it would be expected that the traditional explicit instruction group would display higher scores comparedto the other three groups. Additionally, if analogy learning promoted implicit processing, a difference between the AI and OREI groups should also have emerged. Differences in CMPS scores were seen between tests, however, indicating that the different conditions did potentially influence processing. Transfer 2 scores were the lowest of all four tests, which indicated that the secondary task drew attention away from putting. The increased challenge of the breaking putt during Transfer 1 resulted in the highest scores. The test effect for CMPS scores suggests that the instrument was sensitive to different degrees of *reinvestment* for the putting task.

There were also no significant findings related to the number of explicit rules listed by each group. In combination with the CMPS scores, this finding strongly suggests that the experimental manipulations did not produce measurable differences in implicit or explicit processing. Indeed, the CTRL group listed 62 total rules , which produced an average (5.17 rules per person) similar to the number of rules presented in the traditional explicit instructions . Berry and Broadbent (1988) and Masters (1992) suggested that individuals can utilize an explicit mode of learning even in the absence of explicit instruction. One potential reason for the similarities in rule listing is that many participants may have possessed knowledge of putting derived from previous experience with mini golf. It is also important to recognize that assessments such as the one used to list rules may not truly assess the amount of explicit knowledge a participant used during performance (R.S.W. Masters, personal communication, March 10, 2014). In some cases, some approaches to assess declarative knowledge might lead to omissions. . In others, participants might feel obligated to list several rules to "comply" with the assessment, regardless of the extent to which they relied on explicit processes during performance.. Some researchers (Masters & Poolton, 2012; Maxwell, Masters, Kerr, & Weedon, 2001; Zhu et al., 2011) have recommended the adoption of more sophisticated indicators of explicit processing that can be employed during performance (e.g., monitoring of technique adjustments of EEG). As Masters and Poolton (2012) noted, there are few if any forms of learning that are exclusively implicit or explicit in nature. Accordingly, they argued that the goal of an instructional approach such as analogy learning should be to induce implicit processes as much as possible during the early stages of learning. The results of the current study, however, indicated that analogy learning resulted in a similar degree of explicit processing compared to the other groups. Despite this, both the AI and OREI groups showed learning benefits presumably related to attentional control. These results suggest that instructional length or complexity and the resulting attentional load may have played an important role in previous demonstrations of the benefits of analogy instruction. The notion that the accumulation of declarative knowledge inhibits motor learning may therefore be fundamentally flawed. Brief instructions (i.e., a single analogy or single explicit statement) might allow participants to more effectively focus attentional during performance. Such "attentional simplification" may interact with the implicit or explicit processes that are purported to occur *during* performance. Currently, there is no direct measure of these processes, but the larger transfer benefit seen for the AI group compared to the OREI group indicated that something more than attentional control was involved. Future research should be designed to further assess the combined and independent effects of information content of instructions and the nature of the processing they are thought to promote. The current study demonstrated that the amount of information can be confounded across instructional conditions and so provided insight into the mechanisms underlying the differential effects of manipulations used in the *implicit learning* research.

Limitations

Although this study was designed based upon the considerations of previous research, it features several limitations. This study was conducted under simulated putting conditions in a laboratory setting and it is unclear how these results would transfer to a real-world setting. Participants were asked to learn a straight golf putt in 300 trials over two days. This format constitutes far less time and variety than an individual would utilize if he or she wishes to learn the task for practical purposes. As a result, some participants reported becoming bored or disinterested in the task during acquisition, which may have affected performance. Additionally, participants were screened for prior experience with the task of putting, but several had experience with mini golf which could have increased the amount of declarative knowledge they possessed prior to performing the task. Finally, participants in the study were not pre-tested in order to rule out initial group differences. Therefore, it is possible that observed group effects were the result of pre-existing differences in putting skill.

Recommendations for Future Research

Recommendations for future research are based on conclusions, limitations, and observations from the current study.

1. While novice participants may report having little or no formal experience or practice playing golf (including putting), many have previously played mini golf or have some knowledge about what a putting stance or grip entails. As a result, participants may follow and subsequently list their own "instructions" or "rules" for performing the task. A truly novel motor task might be better suited to investigating the effects of instruction on implicit and explicit motor learning strategies.
2. In post-training interviews, several participants reported becoming bored or disinterested in the task during acquisition. While a straight 10-foot golf putt may be initially challenging for a learner, it can become monotonous in the later blocks of acquisition.

Having participants learn a breaking putt would not only be more externally valid, but might also help improve participant motivation and interest.

3. In order to further test the potential moderating effects of attentional load on implicit and explicit instruction strategies, future studies may consider introducing an incremental explicit instruction group, in which a list of 6 (or more) rules are introduced incrementally over time rather than all at once at the beginning of acquisition. Such participants should, in theory, accumulate the same amount of explicit knowledge as a traditional explicit participant.
4. Additionally, in order to further test the potential moderating effects of attentional load on implicit and explicit instruction strategies, future studies should investigate instructions of varying complexities by altering the length or word content of statements that participants are asked to remember and subsequently follow. Such a study might elucidate the point at which the heuristic benefits of an analogy as a form of instruction might be lost due to increased conscious processing and/or demands on working memory.
5. Future studies should include measures of implicit and/or explicit processing during acquisition to strengthen causal inferences about the differential effects of such processing.

REFERENCES

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review*, *89*, 369-406.

Attneave, F. (1959). *Applications of information theory to psychology*. New York: Holt.

Baddeley, A.D. (1966). The capacity for generating information by randomization. *Quarterly Journal of Experimental Psychology*, *18*, 119-129.

Baddeley, A.D. (1992). Working memory. *Science, 31,* 556-559.

Baumeister, R. F. (1984). Choking under pressure : Self-consciousness and paradoxical effects of incentives on skilful performance. *Journal of Personality and Social Psychology*, *46*, 610-620.

Baumeister, R.E, & Showers, C.]. (1986). A review of paradoxical performance effects: Choking under pressure in sports and mental tests. *European Journal of Social Psychology, 16,* 361-383.

Beek, P.J. (2000). Toward a theory of implicit learning in the perceptual-motor domain. *International Journal of Sport Psychology, 31*, 547-554.

Beilock, S.L., & Carr, T.H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General*, *130* (4), 701-725.

Beilock, S.L., Wierenga, S.A., & Carr, T.H. (2002). Expertise, attention, and memory in skill execution: Impact of novel task constraints on dual-task performance and episodic memory. *The Quarterly Journal of Experimental Psychology*, *55A* (4), 1211-1240.

Berry, D.C., & Broadbent, D.E. (1988). Interactive tasks and the implicit-explicit distinction. *British Journal of Psychology*, *79*, 251-272.

Berry, D.C., & Broadbent, D.E. (1984). On the relationship between task performance and associated verbalizable knowledge. *The Quarterly Journal of Experimental Psychology*, *36A*, 209-231.

Berry, D.C., & Broadbent, D.E. (1987). The combination of explicit and implicit learning processes in task control. *Psychological Research*, *49*, 7-15.

Berry, D.C., & Dienes, Z. (1993). *Implicit learning: Theoretical and empirical issues*. Hove, England: Erlbaum Associates, Inc.

Bright, J.E.H., & Freedman, O. (1998). Differences between implicit and explicit acquisition of a complex skill under pressure: An examination of some evidence. *British Journal of Psychology*, *89*, 249-263.

Broadbent, D.E. (1977). Levels, hierarchies, and the locus of control. *Quarterly Journal of Experimental Psychology, 29, 181-201.*

Capio, C.M., Poolton, J.M., Sit, C.H.P, Holmstrom, M., & Masters, R.S.W. (2011). Reducing errors benefits the field-based learning of a fundamental movement skill in children. *Scandinavian Journal of Medicine and Science in Sports*, *23*: 181-188.

Cooke, A., Kavussanu, M., McIntyre, D., & Ring, C. (2010). Psychological, muscular, and kinematic factors mediate performance under pressure. *Psychophysiology*, *47*, 1109-1118.

Day, R.E. (2005). Clearing up "implicit knowledge": Implications for knowledge management, information science, psychology, and social epistemology. *Journal of The American Society for Information Science and Technology*, *56*(6): 630-635.

Dienes, Z., Broadbent, D. & Berry, D.C. (1991). Implicit and explicit knowledge bases in artificial grammar learning. *Journal of Experimental Psychology* : *Learning, Memory and Cognition, 17*, 875-887.

Fitts, P., & Posner, M. (1967). *Human Performance*. Belmont, CA: Brooks/Cole.

Frensch, P.A. (1998). One concept, multiple meanings. On how to define the concept of implicit learning. In Stadler, M.A., & Frensch, P.A. (Eds.), *Handbook of implicit learning* (pp 47-104). Thousand Oaks, CA: Sage

Fresnch, P.A., & Runger, D. (2003). Implicit leanring. *Current Directions in Psychological Science*, *12*, 13-18.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, *7*, 155-170.

Green, T.D., & Flowers, J.H. (1991). Implicit versus explicit learning in a probabilistic, continuous fine-motor catching task. *Journal of Motor Behavior*, *23*, 293-300.

Green, T.D., & Flowers, J.H. (2003). Comparison of implicit and explicit learning processes in a probabilistic task. *Perceptual and Motor Skills*, *97*, 299-314.

Gucciardi, D.F., & Dimmock, J.A. (2008). Choking under pressure in sensorimotor skills: Conscious processing or depleted attentional resources? *Psychology of Sport and Exercise*, *9*, 45-59.

Gwet, K.L. (2012). *Handbook of inter-rater reliability: The definitive guide to measuring the extent of agreement among raters, (3rd ed.)*. Gaithersburg, MD: Advanced Analytics.

Hasher, L., & Zacks, R.T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General*, *108*, 356-388.

Hayes, N.A., & Broadbent, D.E. (1988). Two modes of learning for interactive tasks. *Cognition*, *28*, 249-276.

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

Karmiloff-Smith, A. (1986) From meta-processes to conscious access: Evidence from children's metalinguistic and repair data. *Cognition*, *23*: 95–147.

Knowles, W. B. (1936). Operator loading tasks. *Human Factors*, *5*, 151-161.

Koedijker, J.M., Oudejans, R.R.D., & Beek, P.J. (2007). Explicit rules and direction of attention in learning and performing the table tennis forehand. *International Journal of Sport Psychology, 38,* 227–244.

Koehn, J.D., Dickinson, J., & Goodman, D. (2008). Cognitive demands of error processing. *Psychological Reports, 102*, 532-538.

Komar, J., Chow, J.Y., Chollet, D., & Seifert, L. (2014). Effect of analogy instructions with an internal focus on learning a complex motor skill. *Journal of Applied Sport Psychology*, *26*, 17-32.

Lam, W.K., Masters, R.S.W., & Maxwell (2010). Cognitive demands of error processing associated with preparation and execution of a motor skill. *Consciousness and Cognition*, *19*, 1058-1061.

Lam, W.K., Maxwell, J.P., & Masters, R.S.W. (2009). Analogy learning and the performance of motor skills under pressure. *Journal of Sport and Exercise Psychology*, *31,* 337-357.

Lam, W.K., Maxwell, J.P., & Masters, R.S.W. (2010). Probing the allocation of attention in implicit (motor) learning. *Journal of Sports Sciences*, *28*(14), 1543-1554.

Law, J., Masters, R., Bray, S.R., Eves, F., & Bardswell, I. (2003). Motor performance as a function of audience affability and metaknowledge. *Journal of Sport & Exercise Psychology, 25,* 484–500

Lee, T.D., & Swinnen, S.P. (1993). Three legacies of Bryan and Harter: Automaticity, variability and change in skilled performance. In J.L. Starkes and F. Allard (Eds.), *Cognitive Issues in Motor Expertise* (pp. 295-315). Amsterdam: Elsevier.

Lewicki, P., Czyzewska, M., & Hoffman, H. (1987). Unconscious acquisition of complex procedural knowledge. *Journal of Experimental Psychology: Learning, Memory and Cognition, 13*(4), 523-530.

Lewicki, P., Hill, T., & Czyzewska, M. (1992). Nonconscious acquisition of information. *American Psychologist, 47*(6), 796-801.

Liao, C., & Masters, R.S.W. (2001). Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences, 19*, 307−319.

MacMahon, K.M.A., & Masters, R.S.W. (2002). The effects of secondary tasks on implicit motor skill performance. *International Journal of Sport Psychology, 33,* 307–324.

Martens, R., Burton, D., Vealey, R.S., Bump, L.A., & Smith, D.E. (1990b). Development and validation of the Competitive State Anxiety Inventory-2 (CSAI-2). In R. Martens, R.S. Vealey, & D. Burton (Eds.), Competitive anxiety in sport (pp. 193-208). Champaign, IL: Human Kinetics.

Masters, R.S.W. (1992). Knowledge, knerves, and know-how: The role of explicit and implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology*, *83*, 343-358.

Masters, R.S.W. (2000). Theoretical aspects of implicit learning in sport. *International Journal of Sport Psychology, 31*, 530-541.

Masters, R.S.W., & Liao, C. (2003). Chunking as a characteristic of implicit motor learning. In R. Stelter (Ed.), *New approaches to exercise and sport psychology: Theories, methods, and applications* (p. 137). Copenhagen, Denmark: University of Copenhagen.

Masters, R. S. W., & Maxwell, J. P. (2004). Implicit motor learning, reinvestment and movement disruption: What you don't know won't hurt you? In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research, theory and practice* (pp. 207- 228). London: Routledge.

Masters, R.S.W., & Maxwell, J.P. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology*, *1*(2), 160-183.

Masters, R.S.W., Law, J., & Maxwell, J. (2002). Implicit and explicit learning in interceptive actions. In K. Davids, G. Savelsbergh, & J. van der Kamp (Eds.), *Interceptive actions in sport: Information and movement* (pp. 126-143). London: Routledge.

Masters, R.S.W., & Poolton, J.M. (2012). Advances in implicit motor learning. In N.J. Hodges & A.M.Williams (Eds.), *Skill acquisition in sport: Research, theory, and practice (2nd ed.)* (pp. 59-75). New York: Routledge.

Masters, R.S.W., Poolton, J.M., Maxwell, J.P., & Raab, M. (2008). Implicit motor learning and complex decision making in time-constrained environments. *Journal of Motor Behavior*, *40*(1), 71-79.

Masters, R.S.W., Poolton, J.M., & Maxwell, J.P. (2008). Stable implicit motor processes despite aerobic locomotor fatigue. *Consciousness and Cognition*, *17*, 335-338.

Maxwell, J.P., Masters, R.S.W., & Eves, F.F. (2000). From novice to know-how: A longitudinal study of implicit motor learning. *Journal of Sports Sciences*, *18*(2), 111-120.

Maxwell, J.P., Masters, R.S.W., & Eves, F.F. (2003). The role of working memory in motor learning and performance. *Consciousness and Cognition*, *12*, 376–402.

Maxwell, J.P., Masters, R.S.W., Kerr, E., & Weedon, E. (2001). The implicit benefit of learning without errors. *The Quarterly Journal of Experimental Psychology*, *54A* (4), 1049-1068.

Maxwell, J.P., Masters, R.S.W., & Poolton, J.M. (2006). Performance breakdown in sport: The roles of reinvestment and verbal knowledge. *Research Quarterly for Exercise and Sport*, *77*(2), 271-276.

Miller, G.A. (1955). Note on the bias of information estimates. In Quastler, H. (Ed.), *Information Theory in Psychology*. Glencoe, Illinois: Free Press.

Mullen, R., & Hardy, L. (2000). State anxiety and motor performance: Testing the conscious processing hypothesis. *Journal of Sports Sciences*, *18*(10), 785-799.

Nissen, M.J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19*, 1-32.

Nissen, M. J., Willingham, D., & Hartman, M. (1989). Explicit and implicit remembering: When is learning preserved in amnesia? *Neuropsychologia, 27,* 341-352.

Ong, N.T., Lohse, K.R., Sze, A.F.S., & Hodges, N.J. (2013). Investigating self-efficacy in an errorless learning protocol. Unpublished manuscript, School of Kinesiology, University of British Columbia, Vancouver, Canada.

Otten, M. (2009). Choking vs. clutch performance: A study of sport performance under pressure. *Journal of Sport and Exercise Psychology*, *31*, 583-601.

Pew, R.W. (1974). Levels of analysis in motor control. *Brain Research*, 71, 393-400.

Poolton, J.M., & Zachry, T.L. (2007). So you want to learn implicitly? Coaching and learning through implicit motor learning techniques. *International Journal of Sports Science and Coaching, 2*, 67-68.

Poolton, J.M., Masters, R.S.W., & Maxwell, J.P. (2005). The relationship between initial errorless learning conditions and subsequent performance. *Human Movement Science*, *24*, 362-378.

Poolton, J.M., Masters, R.S.W., & Maxwell, J.P. (2006). The influence of analogy learning on decision-making in table tennis: Evidence from behavioural data. *Psychology of Sport and Exercise, 7,* 677−688.

Poolton, J.M., Masters, R.S.W., & Maxwell, J.P. (2007). Passing thoughts on the evolutionary stability of implicit motor behaviour: Performance retention under physiological fatigue. *Consciousness and Cognition*, *16*, 456-468.

Raab, M. (2003). Decision making in sports: Influence of complexity of implicit and explicit learning. *International Journal of Sport and Exercise Psychology, 1*, 310−337.

Rathus, J.H., Reber, A.S., Manza, L., & Kushner, M. (1994). Implicit and explicit learning: Differential effects of affective states. *Perceptual and Motor Skills, 79*(1), 163-184.

Reber, A.S. (1993). *Implicit Learning and Tacit Knowledge*. Oxford: Oxford University Press.

Reber, A.S. (1992). The cognitive unconscious: An evolutionary perspective. *Consciousness and Cognition*, *1*, 93–133.

Reber, A. S. (1989) Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General, 118*, 219-235.

Reber, A.S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 6*, 855-863.

Reber, A.S. (1976). Implicit learning of synthetic languages: The role of instructional *set. Journal of Experimental Psychology: Human Learning and Memory*, *2*, 88-94.

Reber, A.S., Kassin, S.M., Lewis, S., & Cantor, G. (1980). On the relationship between implicit and explicit modes of learning a complex rule structure. *Journal of Experimental Psychology: Human Learning and Memory*, *6*(5), 492-502.

Reber, A.S., Walkenfield, F.F., & Hernstadt, R. (1991). Implicit and explicit learning: Individual differences and IQ. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(5), 888-896.

Reza, F. (2010). *An introduction to information theory*. New York, NY: Dover.

Roberts, P. L., & MacLeod, C. (1998). Automatic and strategic retrieval of structure knowledge following two modes of learning. *Quarterly Journal of Experimental Psychology*, *52*, 31–46.

Schmidt, R.A., & Lee, T.D. (2011). *Motor control and learning: A behavioral emphasis (5th ed.)*. Champaign, IL: Human Kinetics.

Schmidt, R.A., & Lee, T.D. (2014). *Motor learning and performance (5th ed.)*. Champaign, IL: Human Kinetics.

Shucker, L., Ebbing, L., & Hagemann, N. (2010). Learning by analogies: Implications for performance and attentional processes under pressure, *Human Movement, 11*(2), 191-199.

Seger, C.A. (1994). Implicit learning. *Psychological Bulletin*, *115*, 163-196.

Shanks, D.R., & St. John, M.F. (1994). Characteristics of dissociable human learning systems. *Behavioral and Brain Sciences*, *17*, 367-447.

Squire, L.R. (1987) *Memory and Brain*. Oxford University Press.

Thorndike, E.L., & Rock, R.T., Jr. (1934). Learning without awareness of what is being learned or intend to learn. *Journal of Experimental Psychology, 17,* 1-19.

Vine, S.J., Moore, L.J., Cooke, A., Ring, C., & Wilson, M.R. (2013). Quiet eye training: A means to implicit motor learning. *International Journal of Sport Psychology, 44*, 367-386.

Wareing, M., Fisk, J.E., & Murphy, P.N. (2000). Working memory deficits in current and previous users of MDMA ('ectasy'). *British Journal of Psychology, 91*, 181-188.

Wagenaar, W.A. (1972). Generation of random sequences by human subjects: A critical survey of literature. *Psychological Bulletin, 77* (1), 65-72.

Wilson, M.R., & Pearcy, R.C. (2009). Visuomotor control of straight and breaking golf putts. *Perceptual and Motor Skills*, *109*, 108.

Wolpert, D.M., Ghahramani, Z, & Flanagan, J.R. (2001). Perspectives and problems in motor learning. *Trends in Cognitive Science*, *5*, 487-494.

Wulf, G., McNevin, N. H., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Psychology, 54A,* 1143–1154.

Wulf, G., & Schmidt, R.A (1997). Variability of practice and implicit motor learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 987-1006.

Wulf, G. (2007). *Attention and motor skill learning*. Champaign, IL: Human Kinetics.

Zhu, F.F., Poolton, J.M., Wilson, M.R., Maxwell, J.P., & Masters, R.S.W. (2011). Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement. *Biological Psychology, 87*, 66-73.

APPENDICES

APPENDIX A

The effects of explicit and implicit instruction approaches on motor learning

The purpose of this study is to examine the effects of different instructional approaches on the performance and learning of a motor skill. During this study, you will participate in three separate data collection sessions held on three consecutive days. Each session will last approximately 45 minutes. Data from your performance will be recorded and stored on a personal computer for later analysis.

The task you will be learning will require you to complete a 10-foot golf putt toward a hole. Your goal is to putt the ball so that it comes to rest in the hole. During each of the first and second days, you will complete 150 putts (300 total). During the third day, you will complete a series of four tests to assess how well you learned to putt. Each test will require you to putt the ball 20 times. Following the final test, you will complete a brief questionnaire and interview about your experience. At the end of the last session, you will have the opportunity to learn more about the research project if you so desire.

If you volunteered for this experiment through the SONA Experiment Management System in exchange for course credit, your participation will be reported to that website. The experimenters conducting this study are not directly involved in awarding course credit. They simply report whether or not you participated in the study.

Identifying information in the study records will be kept confidential. Such data will be stored securely and will be made available only to persons conducting the study unless you specifically give permission in writing to do otherwise. The results of this study and de-identified data may be shared in oral or written reports, but no reference will be made which could link you to the study.

If you have questions at any time about the study or the procedures, you may contact Dr. Jeffrey Fairbrother (jfairbr1@utk.edu). The University of Tennessee does not "automatically" reimburse subjects for medical claims or other compensation. If physical injury is suffered in the course of research, or for more information, please notify Dr. Jeffrey Fairbrother (974-3616). If you have any questions about your rights as a participant, contact the Research Compliance Services section of the Office of Research at (865) 974-3466.

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned or destroyed. I have read the above information and agree to participate in this study. I have received a copy of this form.

Participant’s name (please print) ____

Participant’s signature _______________________________ Date ______________

Experimenter’s signature _____________________________ Date ______________

APPENDIX B

Instructional Script

General:
Welcome and thank you for participating in this study. The task you will be learning requires you to complete a 10-foot putt. Your goal is to putt the ball so that it comes to rest in the hole or as close as possible. I will provide you with a brief demonstration and then ask you to putt the ball three times so I can determine your starting skill level. After those first three trials, you will begin practicing. At times, I may provide you with additional instructions or reminders. (Note: During the demonstration, indicate to participants that the ball should be kept on the platform.)

Traditional Explicit Instruction Group

1. Keep your feet shoulder width apart and knees slightly bent
2. Place your right-hand below your left when gripping the club handle
3. Move the club back a short distance then swing the club forward with a smooth action along a straight line
4. Allow the club to continue swinging a short distance after contact with the ball
5. Adjust the speed of your movement so that the correct amount of force is applied
6. When you hit the ball make sure that the putter head is at a right-angle to the direction you want the ball to travel

One-Rule Explicit Instruction Group

Move the club back a short distance and then swing the club forward with a smooth action along a straight line.

Analogy Instruction Group

Keep your body still like a grandfather clock and swing the putter in the same way that the clock pendulum operates.

Control Group

(There are no additional instructions for this group.)

End of each acquisition session:
Thank you for your time today. Please do not mentally or physically rehearse any activities related to putting between now and when you return tomorrow.

Confirm scheduled time for Day 2 or 3.

First Retention Test

Welcome back. Thank you again for your participation. Today you will be performing under several different conditions to test your putting performance. First, you will perform the same putting task that you practiced during the last two days. Your goal is still to try to get the ball into the hole or as close as possible on each attempt.

Breaking Putt Transfer

For this test, you will now putt from the same distance (10 feet), but you will have to adjust your aim to accommodate the elevated contour that you see under the putting surface. Again, your goal is to try to get the ball into the hole or as close as possible on each attempt.

Secondary Task Transfer Test

For this test, you will be putting from 10 feet on a level surface, but you will also be required to complete a second task at the same time. You will hear a tone played at a rate of every three seconds. When you hear the tone, I'd like for you to respond by saying a consonant from the alphabet as quickly as possible. Your goal is to select consonants as randomly as you can. Imagine that you are drawing consonants from a hat one at a time, calling them out, and replacing them, so that on each draw any of the consonants are equally likely to be selected. Please do not use vowels (A,E, I, O, or U), and avoid going in alphabetical order. You can repeat letters but try to speak each letter with the same frequency. Your responses to the auditory tones will be recorded.

Although you will be performing two tasks at once, be sure to focus mainly on your putting. Try not to speed up or slow down your pace as a result of the auditory tones. Your primary goal is still to try to get the ball into the hole or as close as possible on each attempt. Before we get started with both tasks together, you will practice the letter task independently.

Second Retention Test

For this last test, you will again complete the 10-foot putt on a level surface. Your goal is to try to get the ball into the hole or as close as possible on each attempt.

APPENDIX C

Movement Specific Reinvestment Scale (MSRS)
Conscious Motor Processing Subscale
(adapted for putting movements)

Please think about how you felt while performing the **previous block of putts**, then read the following statements and circle the number that best reflects your feelings:

WHILE PUTTING…	Never		Sometimes		Always
I thought about my stroke.	1	2	3	4	5
I reflected about my technique.	1	2	3	4	5
I tried to figure out why I missed putts.	1	2	3	4	5
I was aware of the way my body was working.	1	2	3	4	5
I thought about bad putts.	1	2	3	4	5
I was conscious of my movements.	1	2	3	4	5

APPENDIX D

Questionnaire and Interview Guide

Participant ID #: ________

1. In the space below, please describe in as much detail as possible all the movements, methods, and techniques you remembered using to perform the task. This would include any rules, knowledge, or guidelines that you acquired or became aware of using during the time that you were putting the ball. Try to include all of the factors that you felt were important in making a successful putt and list each one separately.

Questionnaire and Interview Guide

Administer after questionnaire

2. Did you pay attention to anything else when you putted?

3. When you performed the breaking putt moving from right-to-left, what was your strategy?

4. Is there anything else about your experience during this study that you think I should know?

APPENDIX E

Table 22. *Responses to Q1 of Questionnaire and Interview Guide for OREI Participants.*

ID	Response
101	Tried to move the putter a short distance back
	Hit the ball with a straight and steady motion
	Hit with a consistent power
	I think pulling the putter straight back and moving it straight forward was the most important thing.
102	To move the club slightly back and then forward in a smooth straight line
	Not allowing the club head to turn in my hands before or during contact with the ball
	Following through a short distance after contact with the ball
	Keep my head down through ball contact, and only watch the ball trajectory during follow through
103	I never even once looked at the hole before each putt. As long as I followed directions, the ball went into the hole therefore "aiming" was not necessary
	Keeping a good steady, constant rhythm helped as well as I didn't feel like I came off my game or concentration or anything
	follow directions by swinging smooth and straight and following through
104	Straight line
	Follow through
	Tried to focus and display confidence
	Knees slightly bent
	Sometimes took a deep breath
	See the ball going in
	Don't hit it too hard
	Smooth strokes, nice and easy
105	Bring the putter back a short distance and hit the ball in a straight line
	Try to keep my wrists from moving to keep the ball in a straight line
	Hit the ball gently
	Don’t hit the ball too softly
106	I tried to hit the ball as straight as possible.
	I shortened the verbal prompt that was given to me in the beginning.
	I tried to just tap the ball, so I used a lot of movement in my wrists.
	To the best of my ability, I tried to keep my eye on the putter as it made contact with the ball.
107	Line middle of putter up with hole
	Check to make sure putter is in line behind the ball
	Consistent movement back
	Move putter at a consistent speed
	Take a breath before swinging putter
	Knees shoulder width apart
	Slight bend in knees
	Pinky and thumb in an interlocking grip

Table 22. *Continued.*

ID	Response
108	I focused on hitting the ball straight using a straight swing. I focused on a smooth, fluid motion. I focused on having an identical draw back on each putt. I also focused on an identical follow through with each put.
109	I tried to apply the advice that was given during the practice sessions: move the club back at a short distance and swing it through a straight line. Almost always, I looked at the hole before I shifted my focus back to the ball and putted. On the last ball of a round of ten, I would tell myself "I need to end this round on a high note," and usually to my knowledge, I got the ball in the hole on these ones. I tried to swing it in a straight line. I tried to keep the putter close to the ground without touching it when I was swinging.
110	I made sure to have my left hand wrapped around the putter with my right hand over top and my index finger held straight against the putter. My feet positioning was equal distance between the ball. I made sure to line my putter up with the ball then bend at the hip joint over the ball. I tried to keep a rhythmic timing and go at a steady pace. I knew there was a break right before the hole so if I kept the ball speed the same it should result in a made putt.
111	from a right handed putt, right pinky interlocked with left pointer finger on grip legs slightly shoulder width apart knees slightly bent shoulders slightly over knees look at hole (destination), look at ball, deep breath, pull back, try to hit the ball as straight as possible line up the ball with the line on the putter pull back putter about 2-3 inches or so smooth swing deep breath before swing be aware of how it felt for a good/successful putt and how it differed from an unsuccessful putt
112	I always made sure to line up the line on the club with the center of the ball before I putted. I always would pick a spot about 3 to 4 feet ahead of my starting point and focused on hitting the ball along that point.

Table 23. *Responses to Q1 of Questionnaire and Interview Guide for TEI Participants.*

ID	Response
201	Following through with my swing Knees bent One steady swing Putter at a right angle A shorter back swing, and longer follow through Analyzing what I did wrong on bad puts Analyzing what I did right on good puts
202	When I was putting I would make sure I had the correct line to the hole. I also made sure I had the correct movement to the distance between myself and the cup. In doing so I tried my best to make sure I had the best possible shot each and every time. I made sure that every put would go the middle dot every time which would in-turn make the ball go in the hole each and every time.
203	While putting, I tried to remember at all times to bring the club back a short distance Follow through at an angle perpendicular to the direction the ball was traveling. I also tried not to watch the ball after I would put it and focus on the follow through. I think it is important to keep the club in a straight line before and after hitting the ball. If I continued to do that, the ball would continue to travel in a straight line. I also wanted to make sure I wasn't hitting the ball too hard with each put. That was the biggest challenge for me.
204	I made sure I hit the ball centered and tried to sing through in a straight line I made sure my right hand was lower and that’s what I used to move the club Tried to make sure I hit it with just enough speed and force
205	slightly bend my knees feet shoulder width apart hit ball at a right angle hit ball with one smooth stroke
206	Power of swing Alignment Feet distance Hitting ball at right angle Pull back before swing Kept right arm locked Grip Focus on hole Follow thru Keeping in line with dots on mat
207	Slightly bent knees Hold the club with right hand on bottom and left hand on top Hold the club at a right angle to the direction you want it to go Swing the club in a straight line Adjust the force of the swing according to the speed and distance you want it to go

Table 23. *Continued*.

ID	Response
208	Made sure my knees were slightly bent Arms straight Move from the hips, not the arms Continue swinging slightly after striking the ball Right hand below the left Keep my back straight Keep the grip on the club soft Keep the putter head straight and at a 90 degree angle Keep feet should width apart Tap the ball with just enough force to get it in the hole
209	Keep feet shoulder width apart Knees slightly bent Club at a 90 degree angle Move through the putt Line the line on the putter up with the hole Swing the club back behind the ball and follow through after hitting the ball
210	Feet shoulder width apart Bent knees Right hand below left hand on the club Follow through with the club after the shot Face of club at right angle to the hole Adjust speed of the movement if necessary If I missed I thought about how the face of the putter looked when I made contact with the ball and if the angle was not a full right angle I tried to keep my arms straight and not move my head throughout the movement I became more aware of my breathing during each stroke and tried to keep it the same for each shot
211	Before striking the ball, I positioned my hands in front of the ball. I aligned the ball on the putter with my target line. I timed my putting stroke (Count 1 for backswing, count 2 for strike) I aligned my body parallel to my target line. After striking the ball, I followed the path of the ball, and attempted to understand why it did/didn't go in the cup. I kept my head down until I felt the putter strike the ball. I put the ball in the front-center of my stance.
212	Bend my knees swing with enough force to get the ball into the hole Don't let the ball roll farther than the hole and off the elevated surface Keep a tight grip on the club keep the putter in a straight line Look at my target (the hole) keep my right hand below my left on the grip

Table 24. *Responses to Q1 of Questionnaire and Interview Guide for CTRL Participants.*

ID	Response
301	Start with the ball on the center dot. Try not to hit the ball too hard to have it fall of the back Focusing on other the letters while putting reduces your ability to focus on putting Try to hit the ball the same every time
302	Being a beginner I had a lot to learn. How hard to hit the ball was most important. Putting on elevated surface was not as difficult as I expected. Again the ball speed is the key to a successful putt.
303	I tried to keep my arms pretty straight I looked at the hole to visualize the path the ball should take I lined the center of my golf club up with the ball I tried not to hit the ball too hard or too gentle
304	I tried not to think about other things as I was putting Hitting the ball straight down the center points and following through guaranteed my chance of the ball entering the hole Whenever got comfortable in a certain technique that I felt was working I would mess up Thinking too hard about putting strategies/missing the hole messed me up I think relaxing and calming putting would ensure successfully putting
305	I tried to change my stance so that my knees were bent when I was putting the ball. I used the white dots to help guide my line so that I was able to aim better I did not strike the ball as hard because the surface was fairly fast
306	Feet alignment: parallel to each other and pointing the ball Putter direction (which way the face of the putter was pointing) Being aware of how far to swing the putter Over and under compensation when the ball missed the whole Keeping my eye on the putter and ball as I made contact with the ball I felt like I kept my body stiff/rigid as I putted the ball Stance: how I bent my body to be slightly over the ball Focus on the task at hand; attempt to tune out distractions Kept arms straight, did not bend; little movement Some puts I swayed my hips; not consistently making or missing put
307	Pinky fingers laced together with my thumb over the top of the grip After hitting the ball, tried to follow through entirely Shoulder width apart stance Flat back - which was uncomfortable Tried to hit ball each time with the same amount of force
308	My feet straight My arms were straight on the club The ball was straight toward the whole The speed of the ball not to hard but not to slow The line on the club was in the center of the ball

Table 24. *Continued.*

ID	Response
309	Keeping my feet shoulder width apart Making sure my hands were in the correct position holding the putter Lining the putter up with the hole and the other markers on the green After each put analyzed if it was short, long, or went to the left or right and on the next putt trying to rectify what I did wrong the previous time
310	First I found myself trying to determine the best method for holding the golf club. I literally do not have any golf experience so this was totally new to me. The methods I tried was to hold the club lower, and then higher. Each time I putted, I would try to see which direction the ball traveled so that each putt after that I would reposition the putter to accommodate the direction that I wanted the ball to travel. The speed of the ball, I learned was a factor as well. The harder I hit the ball would in some cases cause the ball to jump out of the cup. I felt that the stroke needed to be smooth and even to allow the ball to travel straight as well as not with too much speed. I also would reposition my stance just to relieve some of the fatigue I felt as I maintain a constant standing position. In some cases, I found this helpful and a way to give me time to evaluate the next putt.
311	Hit the ball with the right amount of force Keep the putter straight back and through Try not to hit the carpet
312	Hit through the ball. Don’t try to make it. Just hit it straight and gently, yet hard enough to make it to the hole. Don’t hit too hard. Think of a song while putting. Keeps you from over thinking the putt.

Table 25. *Responses to Q1 of Questionnaire and Interview Guide for AI Participants.*

ID	Response
401	Stood with feet shoulder width apart
	Interlocked my pinky finger and pointer finger as I held the club
	Swung the putter like a pendulum
	Watched the putter hit the ball each time
	Adjusted my putt each time I hit it too hard or too soft
402	Stand still like a grandfather clock, and swing the putter like a pendulum.
	Keep my eyes over the ball
	Keep feet parallel and in line with target
	Follow through with the stroke
	The putting surface is fast, so it requires a soft stroke
403	I tried to keep my feet about shoulder width apart
	I focused on keeping my grip on the golf club the same every time.
	I choked down on the golf club to keep it from hitting the turf, that made a bad putt
	I kept my body square to where I was aiming to keep the golf ball as straight as possible
	I focused on using my right hand to guide the club, keeping my left as support
	I thought about where the ball should hit the hole, I have been told professionals aim to the side of the whole so if they miss it's not too far off.
	I thought about keeping my body still like a grandfather clock
	I thought about swinging the club as if it were the pendulum of a grandfather clock
	I thought about how hard I was hitting the ball to keep it consistent from putt to putt
	I thought about how to make my back more comfortable, as the number of putts increased, I had more pain from my stance
	I focused on keeping the putter square so the ball would travel straight
	I kept the putter from scraping against the ground, this took time to learn
404	Extend the elbow and wrist and keep them in the same line.
	Make sure the club head hit the ball straight.
	Look at the hole each time before putting.
	Swing my arms in a limited range of motion.
405	I tried keeping my entire body rigid like a board.
	I thought about keeping my arms straight but swinging them fluidly like the clock pendulum.
	I focused on the putter contacting the ball.
	When I missed I reflected on whether it was because I hit too hard/not hard enough or if it was my wrist that turned.
	I tired keeping the putter as straight as possible when I contacted the ball.
	If I made a putt, I tried not thinking anything before the next putt and just let my body remember what I did.
	Towards the beginning trials on the third day I repeated my phrase from the two prior days except for the last 20 regular putts, I didn't repeat the phrase near as much.

Table 25. *Continued*.

ID	Response
406	Kept feet squared up in line parallel with the projected path of the ball
	Tried to minimize lower body movement
	Tensed up grip and used only my arms and shoulders to move the club (minimized wrist movement)
	Moved the putter in a straight line back and forth through the ball
	Kept head still
	Used same speed on backswing, impact, and the follow through
	Smaller backswing and longer follow-thru was most effective in controlling the ball's distance
	Envisioned the line and path of the ball before I hit
407	Stand still as a grandfather clock
	Putting the ball like a swing pendulum
	Both feet parallel with each other
	The putter head should be perpendicular to the moving direction of the ball
	Check the direction of the ball before you putting by looking at the hole
	Focus on the ball and putter when you start swing your putter
	Both arm are relaxed
	Right hand using the muscle to control the swing movement
	Left hand hold on the putter but don't give any force, push a little bit when hit the ball
	When you hit the ball, the hitter should contact the center of the ball
	When the putter and the ball contact, you should hear the crispy sound, instead of a dumb sound.
	Personally, I think about nothing but counting the successful trials, and try to repeat the number in my head.
408	I tried keeping my body as still as possible.
	I tried to follow through with the swing completely, even after hitting the ball.
	I kept my feet planted in the same position.
	I had a relaxed grip on the putter.
	I visualized getting the ball to go where I wanted.
	When the green was tilted, I found that if I aimed for a specific spot on the slant, I had a better chance of making the shot.
	I put the ball in exactly the same spot before putting.
	Before moving on, I watched to see where the last ball went, so I could make corrections
	I kept my feet shoulder width apart.
	I kept my knees slightly bent.
	I was careful about how much force I used to putt the ball.
	I took a moment to think about my form before putting each time.
409	Keep my body still like a grandfather clock
	Swing the golf putter in the same way the pendulum moves
	Swinging with enough force to get the ball to the hole, but not too much to get it past the hole
	Keeping the putter straight so the ball would not veer off to either side

Table 25. *Continued.*

ID	Response
410	Striking the correct area of the putter with the ball
	Thinking of the "grandfather clock" pendulum motion
	Finding the correct amount of force to hit the ball
	Keeping the body still while putting
411	I thought about the movement of my arms, much like the directions movement like the clock.
	I focused on the way my shoulder felt when I brought the putter forward, it was an awkward movement/feeling. I knew that I putted properly if the awkward feeling was present.
	The placement of my body needed to be closed to the ball basically in order for me to be in an almost upright position with very little bend. Further back I missed the hole.
412	I would fix my stance so that my feet were about shoulder distance apart
	I would fold the putter with my left hand on top and right hand below with my index finger pointing down
	I would try to align the line in the middle of the putter up with the ball.
	I would hit the ball at a left angle slightly to have it turn right towards the hole.
	I would adjust my force, stance, and grip as needed after reflecting on the previous shot.

Table 26. *Responses to Q2 of Questionnaire and Interview Guide for OREI Participants.*

ID	Response
101	Yes. Any other noise or movement in the room would distract me. I would also be concentrating on putting the ball with good technique, but then my mind would wonder and I would think about random things.
102	I did not pay much attention to anything else; however, I did notice when louder children were passing by the door (though it was quite rare).
103	Putting by itself was easy and I only thought of the directions given before each and every putt. Nothing else needed attention to make the ball in the hole. Putting with the hill was difficult because I was trying to think of how hard to hit it vs. how high up on the hill I needed to put the ball in order for it to go in. The hill in the green was a lot more difficult. When the letters came in to play, it was easy to focus on just those because I already knew how to successfully putt the ball by following a simple routine.
104	Sometimes I was singing a song in my head. Most of the time was determined to do well and just make it in. When we did the consonants verbal exercise I was more focused on the letters than putting. My putting pace is fast so throwing a verbal stimulus that I have to repeat was throwing me off.
105	I paid attention to my wrists and where the hole was so that my wrists were aiming at it.
106	For the most part, I tried to stay focus on the putt. Sometimes thoughts popped into my head about things I had going on which were somewhat distracting.
107	No
108	During the sound test, it was very difficult to focus on the actual putting task. It seemed as if I was focusing on choosing letters that were not in alphabetical order.
109	Yes, I thought about things I needed to get done that day (i.e., topics to teach, homework and research to get done, etc.). During the dual task, I was focused on finding a consonant that I hadn't used before. I also was trying to come up with a strategy where I could successfully do this without repeating a consonant.
110	During the ringing sequence I was thinking mostly about the letter I was going to say.
111	Sometimes I was aware of the people in the room, but my main focus was on the hole, the ball, and how it felt to putt (kinesthetically)
112	I paid attention to my stance, and also my grip.

Table 27. *Responses to Q2 of Questionnaire and Interview Guide for TEI Participants.*

ID	Response
201	Not much, sometimes I would get dizzy and it would distract me. However, I would automatically focus again.
202	Yes I made sure that I had the correct line from the ball to the hole so I basically aimed for a spot on the 10 ft surface where I knew the ball would go in every time.
203	When I was saying the letters, I looked at the letters at the corner of the carpet. I also looked at the middle dot at five feet as the target sometimes.
204	No I just looked at the ball and as I hit I looked at the hole to aim in that direction
205	I paid attention to how far the ball went and how much force to use.
206	Well, I get distracted easily, so sometimes I looked at my toe nail polish. And I usually accidentally listened to the girl in here working on her experiment. And sometimes when it was totally silent I thought about random things from my day…
207	I would start to think about other things and get distracted from the task at hand.
208	Tried to manage my self-talk and anxiety about missing the put by breathing and focusing on technique. I really focused on letting a bad put go and just going back to the basic instructions given to me in order to readjust for the next putt.
209	I tried to watch the ball and follow through with my body
210	The backswing angle of the club if not perfectly straight, and how my arms and shoulders felt during those shots
211	No, not really
212	No I did not pay attention to anything besides the ball, the putter, myself, and the hole

Table 28. *Responses to Q2 of Questionnaire and Interview Guide for CTRL Participants.*

ID	Response
301	No
302	No, tried to concentrate on lining up the putt and how hard I hit the ball.
303	I noticed that I needed to pay more attention to actually putting on the first day of the study. The second day, I was a little more confident in my ability to get the ball in the hole. I was also getting somewhat bored of putting, so I was able to talk more while still focusing on my stroke. Today was "test day," so I wanted to put more effort into each task rather than try to talk. I especially had to focus more on the new tasks such as visualizing angles that the ball should take to get to the hole with the raised surface in the way. The task where I had to say a consonant every three seconds required me to think ahead of the next letter to say, while trying to maintain a straight stroke. Also, I noticed I got distracted when another person came in and out of the room.
304	I did not pay attention to anything else but if my mind was on other things at the time I would more than likely miss the hole. However, when I had to say consonants I paid attention to not miss the tone to hear my cue.
305	I mainly focused the white dots to guide me to the hole.
306	No, except during the consonant recall portion. I wanted to make as many as possible, so I focused on what I needed to do to get the ball in the hole.
307	Listening to the cadence and saying letters The foam piece threw me off and I found myself thinking about that a lot - mostly because I couldn’t tell how high it raised - bad depth perception.
308	No
309	When I had to say different letters it was more difficult because I wasn't totally concentrating on just on the putt, I kept finding myself going to the same letters over and over and thinking of ones I hadn't said yet.
310	I paid attention to the evaluator taking pictures of all the putts that I missed. This gave me the feeling as if I was being graded.
311	Sometimes I got bored with the task and thought about other things I had to do each day.
312	Thought of various songs while putting. And movies that those songs were in.

Table 29. *Responses to Q2 of Questionnaire and Interview Guide for AI Participants.*

ID	Response
401	I don't think I did. I mostly just concentrated on the force with which I hit the ball more so than aiming because I figured if I hit it straight on with the right amount of force it would go in. Sometimes I hit it too hard so it would ring around the cup and roll out and sometimes too soft and it would stop an inch or two from the hole.
402	No
403	I thought about the discomfort I had from taking a golf stance to putt the ball. I also was thinking about a project I'm working on with my job. Most of the time I was attentive to the task and focused all of my attention of putting the ball.
404	Sometimes, I would get in a rhythm and I my mind would no longer focus on my movements and rules. When we did the 3rd test, I did not focus on my putting at all, because I was too focused on trying to figure out what consonant of the alphabet I would say next.
405	I mostly tired to repeat the instructions that I was given before each putt. A few times I caught myself thinking about my form and the slight bump in the carpet.
406	No
407	Counting the successful trials.
408	Only during the test where there was the sound, when I had to say a letter. I was distracted trying to think of letters to say.
409	For the most part, I paid attention to techniques to get the ball in the hole (i.e., the ones mentioned above). However, I sometimes got hung up on missed putts. Also, during the letter task, I could not pay attention to any techniques just super stressed about which letter I would say.
410	Usually I did not pay attention to anything else.
411	Yes, I was distracted by other things going on that day (Ex. tests.)
412	Other than my shot, stance, and grip, the only thing I ever really paid any attention to was my hair because it kept falling in my face. I probably should have just put it up…

Table 30. *Responses to Q3 of Questionnaire and Interview Guide for OREI Participants.*

ID	Response
101	To putt the ball at the middle part of the hump with a medium power. This put the ball in the hole every time. Or, I could hit with less power and farther up the hump, and it would go in. Or with more power and at the bottom of the hump, but this was more difficult to do consistently.
102	I made sure to turn the club head such that when it contacted the ball, the ball would have a curved path up the slope. I also made sure to still move the club backward then forward in a smooth straight line manner.
103	Once the extra "hill" was put on the green, I only made 4/20 shots. Because I was not given clear directions that if followed would result in a hole in one, I did not know how to make the shot. I looked at the hole, then the hill, then at my putter's placement on the ball before each hit. I tried to hit it at an angle each time but had no clear direction on how to putt to have successful shot.
104	To go over the farthest right side because I started out too much to the middle and it was curving left. But once I got it on the far right side at the top of the hill, it was did I hit it at the right speed. You could hit it too hard or too soft on the straight away but this right-to-left break had to be perfect.
105	I tried to hit the ball to the right a little more than normal in order for it to make it into the hole.
106	At first, it was just trial and error. I tested out various speeds and heights on the hill to see which speed and height was the most effective. After I determined the height that would give the ball a proper curve, I aimed the ball for that general area on the hill.
107	Aim a little to the right so the ball would curve left into the hole after going over the small hill
108	I focused on aiming at the dot farthest to the right and hitting it with the same force each time.
109	First, I attempted a normal putt to see how much it altered the direction. Then I tried to hit it in the direction of the curve first (not too much on the inside, but not too much on the outside). I also tried holding the putter at a different angle (about 45 degrees from the "normal" putt).
110	I knew the putt was going to break left after a couple of putts so I turned my toward the right and began putting that way. Once I hit a couple I judged the speed of the break, then I figured out if I aimed in between the 2nd and 3rd dots from the right that I could get the ball pretty close to the hole if the speed was right.
111	To place the ball slightly to the right of the center dot (of the row of dots closest to me), about an inch or so, and it seemed to go in every time I successfully passed through that point on the green
112	My strategy was to find the break and locate a point 3 to 4 feet ahead of the starting point and try to putt the ball along that point every time. I also tried to hit the ball at a medium not too slow or too fast.

Table 31. *Responses to Q3 of Questionnaire and Interview Guide for TEI Participants.*

ID	Response
201	My strategy was to hit the ball at an angle. I barely tweaked the speed of the ball.
202	My strategy was to find out where the ball was breaking then aim for where the ball would go in every time.
203	Hit the ball a little bit harder. Turn the club head a little bit and do not hit the ball straight, but instead hit to the right.
204	I tried to hit it a little harder and move it towards the higher part.
205	Hit the ball harder and a little to the right.
206	I first tried to hit it softly over the lump and let it coast in but I couldn't control it as well as I thought so then I just tried to hit it more forcefully because I could keep it straighter
207	To aim the ball towards the top of the little hill so that it would fall down into the hole, but it was hard to determine the speed that would get it into the hole.
208	The first few puts I hit the ball like normal to see where it would go. Then I figured out that I needed to hit towards the break so that the ball would roll down into the hole. I tried to hit at the two outside white dots and that seemed to provide a good angle for the ball to then go in the hole. I also had to adjust my force. The ball needed to be hit a little bit (but not a lot) harder so that it could get up the break. In order to do all of this, I had to open the angle of the putter head so that the ball would actually go to the outside.
209	I tried to hit it harder to get it up over the slope, and also hit it at an angle to accommodate for the slope.
210	To aim the ball slightly up the hill to roll down into the whole, and to adjust my speed accordingly. Trying to figure out the slight change in angle of the club face was the only thing I changed apart from speed.
211	I tried to balance the force that I hit the ball with the movement of the ball to the left.
212	Aim more right and hit the ball hard enough to make it over the incline and into the hole

Table 32. *Responses to Q3 of Questionnaire and Interview Guide for CTRL Participants.*

ID	Response
301	To hit the ball slightly into the slope so it would curve back towards the hole
302	To get correct speed on ball.
303	At first, my strategy was to angle my aim for the more elevated part of the raised surface. After multiple attempts with this strategy I tried to hit my ball the same as I did without the raised surface, and this worked much better. I also had to adjust how hard I hit the ball with my club. I had to hit a little harder for the ball to stay in a straight path.
304	In the beginning, I tried to aim for the top of the peak to shift my ball into the hole as like a cheating strategy but it worked against me. I then tried to just avoid it all together but I found if I used the same strategy as the regular putting along with using the more downward slope of the peak I was more successful.
305	I focused on somehow getting the ball to the mound, but not striking the ball too hard.
306	My strategy was to curve the ball up the "hill" and try to do it with the right amount of energy to curve back and make it to the hole. The tricky part was determining the amount of effort needed to get the ball up the hill, down and in the right projector to make the hole.
307	I first tried to see if it rolled a certain way if I hit it over the high part. That didn't work, so I tried to hit it harder through the middle. I came closer doing the task that way I thought (hitting it harder).
308	To make sure that the ball was lined up straight and that I didn’t put too much power when striking the ball toward the hole.
309	With each putt I tried to fix what I had done the previous time if the putt did not go in, I either would putt too straight on or go too much to the right and miss on the other side. When I did have one go in I tried to do the exact same motion and hit the ball in the same place as the previous one.
310	My strategy was to be as smooth and straight with my stroke as possible being sure that I would hold the putter as straight as possible. I tried to position both hands to overlap partially so that I could keep the putter from twisting. I also wanted to bend my legs slightly to allow me to twist slightly as I swung the putter.
311	I tried to aim high on the hill and let the slope take the ball down to the cup. It was hard to make it in the cup though.
312	First few were trial and error. Trying to figure out the appropriate angle and velocity. Remaining were trying to repeat the appropriate angle and velocity.

Table 33. *Responses to Q3 of Questionnaire and Interview Guide for AI Participants.*

ID	Response
401	At first I just hit the ball as I did when it was a level surface to see how it would roll. Then I tried to aim it so that it would roll up and over the raised surface and watched the way it rolled towards the cup to figure out where the best place to aim it would be. I decided the best place to hit it was between the middle dot and the next dot immediately to the right of the middle dot, but that I needed to get it a little closer to the right dot than the middle dot.
402	To hit it soft towards the middle of the bank...the farther right you hit the ball, the more speed the ball had towards the cup. (You had to hit it harder because of increased bank the farther right you hit the ball.)
403	I tried to find a spot in the raised portion of the putting green to aim for every time and let the hill do the work for me. I then tried to hit the ball a bit faster towards the lower part of the hill hoping to counteract the movement away from the hole, that didn't work very well. My end strategy was attempting to find the right place where the ball would roll down the hill toward the hole so I was aiming almost off the green to make it happen
404	I was focused on the speed of the ball, and how far I needed to hit it up the hill in order to make the put go in the hole.
405	For the breaking putt, I was using a problem solving/trial and error approach. I tried hitting it harder or lighter and changing the angle of the putter to hit different parts of the hill. Once I found a good angle and amount of force to make it, I tried not thinking and just doing the same motion. When I thought I did the same motion but missed, I would start over again.
406	To aim for the best spot on the top of the break where I thought the ball might follow the resultant decline and get closest to the whole. Also I reduced my speed on the ball in order for it not to gather too much when rolling down the other side
407	Try to make it steady and not change direction, so your arm muscle is a little bit nervous but not intense.
408	Initially, I tried aiming toward the raised area of the green so that the ball would arc toward the hole. I found that if I aimed between the two dots on the far right, I had an easier time making the putt - so I focused on aiming for that space, without changing the force of my swing.
409	I decided to just hit the ball up the hill because of my physics background in 221 and 222, I assumed that it would need to travel approximately in the middle of the hill with enough force to reach the hole. I think I need to retake physics.
410	Determine what portion of the putter to strike the ball with and adjusting the force of the putt in accordance.
411	Make sure the putter was lined up with the ball and my movement was somewhat stiff.
412	Instead of angling my shot slightly to the left, I would try to hit the ball more in the direction of the hill towards the right side and add a little more force.

Table 34. *Responses to Q4 of Questionnaire and Interview Guide for OREI Participants.*

ID	Response
101	The first day, 150 putts of the same thing is a lot. Definitely towards the end I was beginning to lose interest and I think it affected me.
102	No
103	Putting while consistently randomly naming consonants was easier than I figured actually. Because I had so much practice putting 300+ balls beforehand and at my comfortable pace, it was easy to keep that rhythm and actually follow through and make the holes without thinking about it. I only really needed to focus on the letter naming. Thinking back, I don't remember putting the balls so much as to thinking of a consonant to say next and having one or two lined up behind it and trying not to repeat any previously said.
104	I am tired today which probably affected my performance as yesterday I was full of energy thus I did better.
105	I thought I made more putts in the hole when I was saying the letters instead of focusing on just one task.
106	I was wondering the entire time if my stance and form were correct.
107	Having to say the letters while putting made me anxious.
108	I feel much more confident in my putting abilities after this study.
109	During the dual task, I found myself wanting to go at a faster pace. (About one putt for every two beeps, which was faster than my normal pace in practice.)
110	It was really easy to get into a rhythm on days 1 and 2 but on the 3rd day the two variables (saying a letter from the alphabet and the break) made the putts generally harder. However, the hardest out of the two variables was the break more so than speaking a letter from the alphabet.
111	My focus was on where I was going to place the ball and how it felt when I did it successfully, and to replicate that feeling. However, all of that focus shot to hell when I was saying the consonants. Then, my focus shifted to naming correct, random letters rather than the task at hand.
112	There is not anything else I think you should know.

Table 35. *Responses to Q4 of Questionnaire and Interview Guide for TEI Participants.*

ID	Response
201	No
202	No not really, I will use some of the methods here in the future when I play normal golf or putt putt golf.
203	No
204	No
205	Not that I can think of
206	I tried to experiment with hitting ways that I thought could help (like I kept my right arm locked).
207	I don't think so.
208	It was really interesting how much my performance altered during the alphabet task. I really had to rely on my training from the past two days in order to be remotely successful. I relied on my body knowing what to do because my mind was focused on selecting the next constant, even when I tried to re-focus on the putting.
209	Trying to say letters while putting was REAILY difficult. Harder than I thought it was going to be. I don’t even think I watched the ball to see if it went in after each shot.
210	The line of the carpet is slightly off center in terms of the boarding that it is attached to so the peripheral line of sight isn't straight which could play a role if you can't block that out
211	The task with the audio tones was difficult. I found myself wanting to say vowels sometimes.
212	The first two days helped me to get comfortable with the hole distance from the center dot where I placed my ball. By the third day, I caught myself not looking at the hole in order to decide how much force I needed to use in order to make the ball in the hole.

Table 36. *Responses to Q4 of Questionnaire and Interview Guide for CTRL Participants.*

ID	Response
301	No
302	No
303	Overall, I enjoyed the study. It would have been helpful to have some feedback on my form and technique. Also, I think I would have done better if I was given tips on how to get the ball in the hole, especially in the elevated surface task.
304	I think golf could be a relaxing hobby because you cannot successfully putt if you are distracted. I feel that golf requires focus and calm mindset.
305	I think it would be fun if there were more mounds. I think putting at the same place became tedious. I enjoyed putting with the mound.
306	I was able to practice the puts and that helped me gain confidence in my putting skills before the distractions were presented. While still very inconsistent, the introduction of the distractions caused me to feel inadequate while putting, especially during the auditory portion. Now I know why they have the "quiet" rule for golf.
307	Just giving the participant all 20 golf balls at once would be helpful. Otherwise it breaks up the trial…unless that is what you're going for. Then keep doing it in 10's. I think next time you should include a trial with hip shaking. That would really make it better.
308	It was really hard when we had to putt and say that letter it got me to think more on the letters than putting the ball into the hole.
309	No I enjoyed learning how to putt. I have never really done it before.
310	I found the exercise with the beeper and saying a constant very difficult. If I could have said the constants in order, I could have kept up with the process better. I could not concentrate on the putting while trying to remember to say a consonant, or one I had not said while trying to putt at the same time. I found this very frustrating to say the least. The break in between was also a welcome time. This gave me more time to rest as well as evaluate my performance to see what I could do differently to improve my accuracy.
311	Nope
312	Putting is my best and favorite part. I am really good with angles.

Table 37. *Responses to Q4 of Questionnaire and Interview Guide for AI Participants.*

ID	Response
401	The part where I had to say the letters was very difficult. I wasn't even paying attention to whether my ball went in to the cup or not. I was so focused on saying letters that I didn't care whether the ball went in.
402	Yes, I feel that as fatigue began to set in during a testing session, that my putting stroke was affected.
403	I had a roommate who is a pretty competitive golfer. I thought back to what he had told me about golf in the year we lived together and tried to imagine what the pros do that I could mimic. I did not go into the study thinking I would be able to hit many putts but I was surprised by the end of the second day how much more consistently I felt my putts were going where I wanted them.
404	I'm pretty sure I hit the ball better during test 3 than I did on the final test. I thought that was very strange that I wasn't focusing on the movement at all during that test, but I hit the ball much better.
405	When I started the study, I shortened my instructions to "body still, arms like a clock pendulum" but as I got more comfortable I said "keep your body still like a grandfather clock and swing your arms like a clock pendulum."
406	It was a fun study and I feel like my putting has improved.
407	Left thigh and right waist sores after the first study, not sure whether it was because my posture was wrong.
408	I really hated the beeping part. And that I felt like on the second day, that I actually got worse.
409	It is really hard to make a putt, while thinking of consonants. Good study though!
410	No
411	Yes, lack of sleep on the second day had an adverse reaction on my thought processing capabilities.
412	In the second to last trial that involved the recording, it was much harder to focus on my putting. The thing I was most worried about was coming up with another letter, regardless of being told that my primary goal was to make the shot.

Vita

Kevin M. Fisher was born on March 2, 1985 in South Boston, VA. Prior to attending the University of Tennessee (Knoxville, TN), he completed a Bachelor of Arts degree with dual majors in Psychology and Government at the University of Virginia (Charlottesville, VA) and a Master of Science degree in Exercise and Sport Science with a concentration in Sport and Exercise Psychology at the University of North Carolina at Greensboro. In December 2014, he received a Doctor of Philosophy degree in Kinesiology and Sport Studies with a specialization in Sport Psychology and Motor Behavior.