

Heart Rate Variability and Postural Motion as Correlates of  
Competitive Situations in Golf Putting

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## Abstract

Golfers often encounter competitive situations during performance, especially when sinking a putt is required for a win. Putting under pressure can sometimes result in impaired performance, a condition commonly referred to as the “yips.” A competitive environment produces physiological and behavioral changes that can affect performance, but simultaneous measures of heart rate and postural sway variability during a competitive putting event have not yet been examined. This study was guided by embodied cognition theory and assessed changes in postural sway and heart rate measures in experienced and inexperienced golfers in two separate experiments. To foster a competitive environment, participants had the opportunity to win valuable gift cards in both experiments.

In the first experiment, 19 active golfers participated in one to three rounds of golf putts on an outdoor practice green while standing on a balance board and wearing a heart rate monitor. The first two rounds comprised 15 putts each, and participants were told the first round scores would not count while the second round scores would. The top seven performers from the second round advanced to the third round, which utilized a knockout tournament format to determine a winner. Putting performance, postural sway, and heart rate measures were recorded during each round, and gift cards were awarded to the first and second place participants after the final round.

The second experiment involved 20 university students that were not experienced golfers. This experiment followed a similar protocol to the first, but participants attempted five putts from two different distances during each round in an indoor facility. The top eight performers from the second round advanced to the third round for a chance

to win more money. Putting performance, postural sway, and heart rate measures were again recorded, and the Sport Grid-Revised was also included to provide an additional measure of arousal.

Within each experiment, participants with lower postural sway variability had better putting performance in the second round, which involved more pressure than the first round. Participants in the final round tended to have increased heart rate and decreased heart rate variability, showing a greater degree of arousal. Lower heart rate variability was also associated with better performance of short putts in the second experiment. Comparisons between the two experiments showed experienced golfers and beginners differed in measures of postural sway, heart rate, and heart rate variability while putting. These results support the notion that postural motion and physiological change (heart rate responses) are not autonomous systems, but are linked, and are related to golf putting performance in competitive situations. The results are used to discuss the broader implications of embodied cognition in the context of competitive human movement situations.

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## I. Introduction

Golf has become an increasingly popular activity in the U.S. with over 26 million people participating in the game in the year 2000 (Smith et al., 2000). This activity is generally encouraged by medical practitioners because it can be enjoyed by people of all ages and ability levels and involves physical activity, which contributes to better health. Unfortunately, performing under pressure may result in impaired performance, a phenomenon commonly referred to as choking. Beilock (2007) suggests understanding cognitive mechanisms involved in pressure-induced failure will provide more knowledge about choking.

Beilock (2007) describes two main theories to explain choking in sport. Explicit monitoring theories suggest self-consciousness and performance anxiety are increased during stressful situations, interfering with well learned skills that are typically performed automatically. Distraction theories, on the other hand, claim pressure creates a distracting environment that compromises working memory resources available for task performance and shifts the performer's focus to task-irrelevant cues. Beilock contends both of these theories can help explain choking, though the primary cause may depend on the skill level of the performer and the cognitive demands of the skill.

In aiming tasks such as golf putting, choking can lead to a condition known as the "yips," which can harm performance and prevent many golfers from fully enjoying the game. The yips have been defined as any jerk, tremor, or freezing of the upper extremity that interferes with the smooth execution of the putting stroke in experienced golfers (Smith et al., 2003). Since golf is an activity that relies heavily on precision, coordination, and fine muscle movements (Weinberg & Genuchi, 1980), any interference

with the putting motion could have a major impact on performance. After surveying hundreds of experienced golfers, Smith et al. (2000) reported the yips tended to occur during putts that were 5 feet or closer to the hole, and during fast, downhill, or left-to-right breaking putts. They also found the yips could result from tournament play, leading during a tournament, attempting difficult putts, or playing against specific competitors.

Putting performance has been shown to be a significant predictor of overall golf performance, especially when compared to driving ability (Quinn, 2006; Wiseman & Chatterjee, 2006). Since the yips can interfere with putting, golfing performance may be impaired. This could cause frustration and lead some golfers to withdraw from the sport (Smith et al., 2000). In order to address this problem and allow more golfers to perform better and enjoy the game, a better understanding of impaired putting performance under stress is needed.

### **Theories on the Yips**

Few studies have specifically studied the occurrence of the yips. Smith et al. (2000) suggested the yips may result from biomechanical changes in the brain that accompany aging, excessive use of involved muscles, and intense coordination and concentration demands. The yips may also result from a neuromuscular dysfunction known as focal dystonia due to prolonged repetitive and abnormal posture. Dystonia has been defined as a neurological disorder characterized by involuntary movements resulting in spasms, twisting, and posturing of a single or multiple body parts (Smith et al., 2003). The yips may also be exacerbated by anxiety, but Smith et al. (2000) did not hypothesize whether anxiety was a cause or consequence of yips behavior. They did, however, propose that the yips are more likely to be related to anxiety because dystonia is a rare

condition, and many golfers report experiencing the yips. After conducting a small pilot study involving various putting conditions, they found yips-affected golfers had higher heart rate (HR), higher grip force on the putter, and more electromyographic (EMG) activity in forearm muscles than control participants during the putting stroke. Yips-affected golfers also had lower putting performance, and their reported handicaps were higher than nonaffected golfers. A handicap is a systematic measure of a golfer's performance used to assess progress and skill level, and is based on the average score over par that an individual takes to complete an 18-hole round of golf (Cook et al., 1983). A lower handicap represents a higher skill level.

Smith et al. (2003) believed the yips could result from either dystonia or choking, and surveyed a group of 72 low handicap male and female golfers (mean handicaps = 6.7 and 13.1, respectively) with an average age of 52 years with 36 years of playing experience. The researchers classified 40 of the respondents into the dystonia related category of yips (Type I), while 16 participants were classified as suffering from choking or anxiety-related yips (Type II). Fourteen other participants reported both types of symptoms, leading the authors to suggest the yips could be classified on a continuum ranging between focal dystonia and anxiety or choking. Smith et al. (2003) also suggested the individual golfer's perception was important for understanding and treating the problem of the yips. The incidence of reported dystonia surprised the researchers, and they believed many of these participants may have interpreted their problems as physical instead of psychological.

Stinear et al. (2006) designed a study to test the model suggested by Smith et al. (2003). The first experiment involved counterbalanced high and low anxiety conditions.

Anxiety was manipulated through the use of a monetary reward and the presence of a video camera and supposed “expert” to rate performance during the high anxiety condition. In this case, the monetary reward could be removed from the high anxiety condition once a certain number of putts were missed. Twenty-two male and two female golfers (age = 18-75 years, handicap = 0-29) participated in the experiment. Fifteen of the participants reported experiencing yips symptoms and were assigned to either a Type I (dystonia) or Type II (anxiety) group based on the nature of their symptoms. Nine participants reported no previous occurrences of the yips and were placed in a control group. Participants were asked to perform 10 putts at each of four different holes at distances ranging from 2.2 to 2.5 m. EMG activity of forearm muscles was recorded while putting, and a state anxiety survey was completed before and after putting.

Overall, the type of condition didn't significantly affect putting accuracy, but the presence of a monetary reward did affect the control and Type II groups. Once the monetary reward was no longer available in the high anxiety condition, control and Type II participants performed better than when the money was available. The Type I group was not affected by the monetary reward. Cognitive anxiety measures differed between conditions for the control and Type I groups, but Type II participants reported relatively high anxiety in both conditions. All groups exhibited more forearm activity in the high anxiety compared to the low anxiety condition, though Type I participants had higher peak EMG values than control participants in the low anxiety condition. The researchers found the Type I group exhibited abnormally high levels of EMG activity, even in the low stress condition. Also, Type I yips-affected golfers were generally older and more experienced and had lower overall putting accuracy than Type II yips-affected golfers.

These results were further supported in a second experiment that utilized an anticipated response task. The authors concluded Type I yips were related to impaired initiation and execution of movement rather than factors related to performance anxiety. According to the researchers, however, the putting task may have been too difficult in this experiment because putts were only successful about 50% of the time for all groups.

Contrary to Smith et al.'s (2003) notion of the yips continuum, Marquardt (2009) suggested the yips should be classified as a contextual movement disorder (CMD) after studying the putting kinematics of 264 amateur golfers. Marquardt defines the yips as a learned disorder based on fatal movement strategies that introduce an increased level of movement control in what would otherwise be automated movements. This condition leads to jerking movements and is modulated by anxiety. He argues the basic putting movement itself is not disturbed but rather the execution of the movement in a specific context. According to this reasoning, focal dystonia can't explain how the yips can occur in golfers in some contexts but not others. Marquardt suggests different factors can occur and influence each other at the same time, and these factors are connected by a vicious circle which accelerates once it is closed. This vicious circle includes anxiety, overcontrol, interference, and the perception of the problem. According to this model, the initial development of the yips could be related to any of these four factors, and a number of treatment methods could be employed to help yips-affected golfers.

While Marquardt's (2009) model provides a comprehensive explanation for the occurrence of the yips, several limitations are present. The yips are generally believed to occur during putt attempts at relatively short distances, but participants in Marquardt's study putted at a distance of 4 m. Also, the experiment did not involve a condition to

manipulate or measure anxiety in participants, which is a major feature of the yips phenomenon. While the yips are attributed to a number of different factors, the only variable measured in this study was the kinematics of the putting club. Additional research is needed to support Marquardt's model of a vicious circle of the yips.

The theories proposed by Smith et al. (2003) and Marquardt (2009) to explain the yips in golf do differ, but they are similar in the fact that they both claim that characteristics of the individual performer and the performance context can influence putting performance in a competitive situation. This commonality allows for the selection of a theoretical approach to further investigate the relationship between golf putting performance and competitive stress.

### **Theoretical Approach – Embodied Cognition**

While different theories have been proposed to help explain the occurrence of the yips, it is evident that golfers affected by this condition can be influenced by a variety of factors. An appropriate theoretical approach is required to better understand this phenomenon. Based on the array of factors related to the yips and the fact that choking in sport is often attributed to cognitive mechanisms (Beilock, 2007), I propose the embodied cognition (EC) approach is a suitable theory to drive further research in this area.

The theory of EC, while relatively new, has gained popularity in recent decades. As Wilson (2002) points out, traditional cognitive science views the mind as an abstract information processor, and perceptual and motor systems are not considered relevant to central cognitive processes. In this view, knowledge is represented in the brain by abstract or amodal symbols. However, this notion has been criticized by Niedenthal, Barsalou, Winkielman, Krauth-Gruber, and Ric (2005) and Barsalou (2008), who argue

that there is little evidence that the brain contains amodal symbols for cognition. The EC approach, on the other hand, argues that the mind must be understood in the context of its relationship to a physical body that interacts with the world (Wilson, 2002). According to Beilock (2009), cognition is deeply rooted in action, and the EC approach stems from ecological psychology's view of a strong link between perception and action. EC theory stresses the interactions between perception, action, the body, the environment, and other agents, typically during goal achievement (Barsalou, 2008).

Though more researchers are adopting this approach, Wilson (2002) contends that a single definition of EC has not yet been established, and identifies six diverse claims commonly found within EC theory. First, cognition is said to be situated, in that it takes place in the context of a real-world environment that inherently involves perception and action. Wilson does point out however, that cognitive activities such as planning and remembering are not situated. Cognition is also said to be time-pressured, though some situations (e.g., analyzing, planning, assessing) are not under the pressure of a real-time interaction with the environment. Third, because of limited information processing abilities, humans off-load cognitive work onto the environment or exploit the environment to reduce cognitive workload. Humans can make the environment hold or even manipulate information, and then collect this information on a need-to-know basis. Within EC, the environment is considered part of the cognitive system that involves a continuous flow of information between the mind and the world, and the mind alone may not be a meaningful unit of analysis. Another major claim of EC is that the function of the mind is to guide action, and cognitive mechanisms such as perception and memory must be understood in terms of their contribution to situation-appropriate behavior.

Finally, off-line cognition is believed to be body based. According to this claim, even when the mind is decoupled from the environment, activity of the mind is grounded in mechanisms that evolved for interaction with the environment, such as sensory processing and motor control. Wilson advises that although these principles of EC have gained support, they can not explain all of cognition.

Although EC may involve many diverse claims, Niedenthal et al. (2005) contend the main idea underlying all theories of EC is that cognitive representations and operations are grounded in their physical context. This results in what they refer to as a central sense of embodiment, in which the brain has modality-specific systems consisting of sensory systems that underlie the perception of a current situation, motor systems that underlie action, and introspective systems that underlie the conscious experiences of emotion, motivation, and other cognitive operations. Related to this claim is perceptual symbol systems (PSS) theory, which purports that modality-specific states in the brain that represent perception, action, and introspection in online situations are also used to represent these situations during offline processing that underlies memory, language, and thought. In this view, knowledge is represented and processed by simulations of perceptual, motor, and introspective experience in the mind (Niedenthal et al., 2005).

Anderson (2007) claims cognitive functioning can be better understood by considering its evolutionary history, and suggests cognition is an adaptive process that enhances the chance for survival by allowing us to more effectively cope with the environment. In this respect, the coupling between perception and action is essential for cognition because the primary organ system that supports cognition (the central nervous system) is also responsible for perception and coordination and control of actions.

Anderson also contends that cognitive systems evolved as a behavioral control system, and our thinking about various purposes such as time, states, or change is rooted in our thinking about space, which emphasizes the importance of considering the surrounding environment.

Though the EC approach has broad implications, Beilock (2008, 2009) notes an absence of motor-related topics in cognitive psychology, and suggests research in motor skill expertise and acquisition would greatly benefit the advancement of EC theories. Beilock (2008) also stresses the importance of experience when considering cognitive processes, and states that experience will fundamentally change the extent to which cognition is grounded in action. Since EC posits that representations of objects and events are built on a system of activations that were active during the actual perception of and interaction with those objects and events, Beilock (2008) argues individuals with varying levels of experience will represent that information in different ways.

Aroujo and Davids (2004) contend human movement systems can be considered as dynamical systems composed of many interacting parts, and within the EC framework information detected in the environment is scaled in relation to body parts and action capabilities as well as the relative location to other important objects, surfaces, or people in the environment. They describe actions as inherently goal-directed behaviors that are embedded in specific performance contexts and embodied in the individual performer's movement system, and suggest that it is important to consider action itself as part of a continuous dynamic process in the relationship between the athlete and the environment.

Aroujo and Davids (2004) also mention the importance of considering constraints related to motor skill performance within the EC framework. Newell (1986) identified

three categories of constraints that determine the movement capabilities of individuals. Organismic or individual constraints, environmental constraints, and constraints of the task itself all limit the capacity for motor skill performance. The relationship between these three types of constraints is also synergistic, as interactions between them determine how motor skills can be performed. According to Araujo and Davids, a person learning a skill in sport can be described as a dynamical movement system that is searching for stable and functional states of coordination to achieve a specific task goal. They argued individual, environmental, and task constraints can alter the coordination patterns used by performers during skill performance, and the interaction of these constraints on the neuromuscular system results in the emergence of optimal behaviors during goal-directed activity. In this view, skilled behavior is considered at the level of the performer-environment relationship and emerges from the interaction of individuals with different constraints over time (Araujo & Davids, 2004).

The claims made by Araujo and Davids (2004) provide a strong case for the use of EC theory in motor skill performance research. Smith et al. (2003) and Marquardt (2009) both proposed that impaired putting performance under stress was related to characteristics of the individual performer as well as the context of the performance environment. Considering the embodied view coupled with the concept of constraints, if actions are embedded in specific contexts and embodied in the performer's movement system, changes in environmental constraints will interact with individual and task constraints to influence behavior and will ultimately impact the coordination patterns of the goal-directed actions. Choking in sport is often attributed to cognitive mechanisms (Beilock, 2007), but golf putting requires perception of and action in the environment. An

embodied approach would emphasize the importance of studying the actions of the performer in the specific environment. Since the environmental context has a significant influence on golf putting performance, the EC approach can be used to address the issue of how changes in the environment are related to embodied processes involved in the goal-directed behavior, and how these changes might affect the coordination patterns of the actions and ultimately the performance of the individual. To gain a better understanding of the interaction between the performer and the environment, studying changes in the actions of the performer that result from different environmental constraints will provide a more comprehensive understanding of golf putting behavior in different contexts.

Due to the multiple factors involved in the competitive stress and the occurrence of the yips in golf putting, EC is a fitting approach for studying this phenomenon. EC's emphasis on understanding interactions between cognitive processes, actions of the body, and the environment will aid research concerned with the performance of perceptual motor skills in different situations. As Beilock (2008) noted:

Not only does embodied cognition open a new kind of window into sport psychology by predicting the interaction of the mind, body, and environment in ways that conventional information processing theories do not, but sport science work is able to give back to the embodied movement by demonstrating what experience on the playing field buys one on the pitch and beyond. (p. 28)

## **Purpose of the Study**

Putting is a significant predictor of overall performance in golf, and performing in a competitive situation may affect the execution of this skill and in some cases result in the yips. Golf putting performance is a complex perceptual motor skill that is influenced by many factors, including cognitive processes, bodily states, and the competitive environment. The EC approach accounts for all of these factors and can be employed to help better understand how golf putting performance is influenced by a competitive environment.

Various factors associated with golf putting performance have been examined in the research literature. In the next chapter, a thorough review of this research is presented and significant factors that influence golf putting performance are identified and discussed. The use of EC theory is also highlighted to help explain how it can be employed to gain a better understanding of golf putting performance in competitive situations. This will provide the rationale for the present research.

## **Central Research Question and Hypotheses**

Specifically, this study asked, do postural sway variability, HR, and heart rate variability (HRV) change as a function of the competitive setting in golf putting? Further, do these changes affect performance? From these two research questions, the following five hypotheses, based on the function of the competitive environment, were:

- 1) Postural sway variability will decrease in a more competitive condition;
- 2) HR (beats per minute) will increase in a more competitive condition;
- 3) HRV will decrease in a more competitive condition;

- 4) Lower postural sway variability will be associated with better putting performance; and
- 5) Lower HRV will be associated with better putting performance.

Two experiments were conducted to test these hypotheses and address the research question. The first experiment involved experienced golfers and took place at an outdoor practice putting green, while the second experiment involved inexperienced golfers in a laboratory setting. The design and methodology of these experiments are described in Chapter 3. The results of these experiments are discussed in Chapter 4, and overall conclusions are provided in Chapter 5.

## II. Review of Literature

### The Skill of Golf Putting

Golf is a popular activity and the goal of golf putting is relatively straightforward, leading many researchers to study a myriad of factors related to golf putting performance. Though the goal of the putt may be simple, the actual execution of the putting task is considered to be a complex motor task, and several studies have focused specifically on the putting motion. Karlsen, Smith, and Nilsson (2008) argued instructional literature on putting was often perceived as anecdotal and based on observations by top coaches and players rather than on published scientific research. They identified four phases of the putting process that contribute to variability in putting direction: green reading, aim, stroke, and ball roll. After analyzing the putting motion of 71 elite golfers (mean age = 21.7 years, mean handicap = 1.8), they determined the stroke was not the most important aspect of putting, and suggested elite golfers may instead need to focus more on green reading or aiming when practicing their putting skills. Another study by Karlsen and Nilsson (2008) supported these claims after studying 43 expert golfers (mean age = 20.2 years, mean handicap = 2.8) in two separate putting tests. These findings demonstrate the importance of green reading when attempting putts in golf, but they can not explain how the actual execution of the putting stroke is affected by a competitive environment that places stress on performers.

While the ability to properly read the green may have a greater impact on putting performance than putting technique, it is the execution of the putting stroke that is impaired when the yips occur, and studying the nature of the putting motion is still an important aspect of understanding putting under stress. Delay, Nougier, Orliaguet, and

Coello (1997) compared club movements between experts and novice golfers as they putted to targets at different distances. They found the path of the club was different between novices and experts, as the movement time was shorter and putting velocity was quicker for novices. Experts also had more stable putting movements across trials. Since experts and novices exhibited different putting motions, it can be concluded that putting technique is still an important predictor of success. While these studies shed some light on important aspects of the execution of the skill of golf putting, none of them considered the influence of a competitive environment. However, other research has analyzed the effects of various constraints on golf putting.

### **Cognitive Aspects of Golf Putting**

According to Beilock and Carr, (2004), many of the differences between performers of varying skill levels can be explained by cognitive mechanisms. They note that paying too much attention to skill execution may actually impair performance in experts, and claim high-level skills based on automated or proceduralized skill representation may be more susceptible to the negative consequences of performance pressure compared to less practiced performances. The goal of golf putting is relatively simple, but the execution of the putting skill is a complex perceptual motor task. For these reasons golf putting has been involved in a number of studies related to theories of attention and learning.

Researchers have utilized golf putting tasks to better understand how attentional processes relate to skill performance. Since golf putting is a complex task, it can be argued that a performer must devote a sufficient amount of attention to the task during performance in order to be successful. Neumann and Thomas (2009) contended

attentional processes have emerged as a key psychological factor important for skill learning, and measured electrical activity of the heart with an electrocardiogram (ECG) along with respiratory effort in groups of elite, experienced, and novice golfers while they performed 20 2.4 m putts. Elite and experienced golfers performed better than novices and decelerated their HR more than novices prior to putting. Groups did not differ in mean HR or respiration measures, but elite and experienced players had higher HRV measures when putting, possibly demonstrating a lower attentional effort toward the task compared to novices. The researchers were unable to determine if novices invested greater attentional effort or were under more stress compared to experienced golfers while putting, but concluded there were certain psychophysiological patterns associated with the attainment of skilled performance in golf putting, and some of these were unique to attaining an elite level in the sport.

Other studies have manipulated putting conditions to assess the relationship between attention and performance by asking participants to perform an additional task while putting, which is referred to as a dual-task situation. Beilock, Wierenga, and Carr (2002) compared the performance of 42 experienced golfers and 42 novices in single and dual-task situations. To add novelty to the putting task, some participants also used a “funny” putter, which had a different shape than a normal putter. Novices in both putter groups had decreased putting performance during the dual-task, while the experts’ putting performance was not affected when dual-tasking with the normal putter. Expert golfers, however, did experience impaired performance while dual-tasking with the funny putter. The authors believed the dual-task strained the attentional capacity of the experts when they used the funny putter, which lead to decreased putting performance. Toner and

Moran (2011) also showed that dual-tasking could impact golf putting in 14 male expert golfers, as participants tended to have slower and more variable putting motions when asked to make technical adjustments to their putting stroke, though putting performance was not affected. In a second experiment, 18 male expert golfers showed decreased putting performance when asked to consciously monitor the path of the club head during the putting motion. Toner and Moran (2011) claimed different forms of conscious processing may have differential influences on putting performance in expert players.

Anxiety can interfere with attentional processes, and the impact of anxiety on attention and performance has received some attention in golf putting research. Wilson, Smith, and Holmes (2007) asked 28 golfers between the ages of 19 and 60 (handicaps from 10 to 18) to perform 20 putts ranging from 3 to 3.6 m in low and high pressure conditions. A monetary reward, video camera, and comparison to other participants were used in the high pressure condition. Participants completed anxiety scales and self-report questionnaires before putting, after the 10<sup>th</sup> putt, and after the last putt in each condition. HRV was also measured while putting to assess attention. After all putting conditions were completed, participants were split into low and high trait anxiety groups for analysis. Both groups reported higher state anxiety in the high pressure condition compared to the low pressure condition, and this was especially evident for the high trait anxiety group. HRV was not significantly different between the high and low pressure conditions, but HRV was lower while putting when compared to a control condition, likely showing a higher level of attention while participants putted. Overall, putting performance was not significantly different between groups or across conditions, though

the high trait anxiety group tended to perform worse in the high pressure task compared to the low pressure task.

While Wilson et al. (2007) did not find a significant effect of anxiety on putting performance, Mullen, Hardy, and Tattersall (2005) showed anxiety influenced the performance of 24 male golfers (19-62 years, handicap = 10-21) as they completed three blocks of 10 putts in task-relevant (utilize coaching points), task-irrelevant (count high pitch tones) and single task (normal putting) conditions during both evaluative (high anxiety) and neutral (low anxiety) situations. In the evaluative condition, participants were told the best performers would receive a monetary reward and would be judged by a panel, while the reward and judging panel were not present in the neutral condition. The researchers found HRV was higher in the dual-task low anxiety conditions and concluded this condition was less attention demanding than the evaluative condition, though self-reported effort was not significantly different between conditions. Also, putts were less accurate in both high anxiety dual-task conditions compared to the normal putting conditions and the low anxiety dual-task conditions, supporting the notion that anxiety interferes with performance.

Cognitive mechanisms are said to play a significant role in skilled motor performance (Beilock & Carr, 2004), and the previously mentioned studies demonstrate the important relationship between attention and performance. However, other studies have utilized a more direct measure of cognitive activity by examining measures of brain activity during golf putting performance. This is often accomplished through the use of an electroencephalogram (EEG), which records different frequency ranges in the brain.

Beta waves typically correspond to intense mental activity, while alpha waves are predominant during a relaxed state (Shelley-Tremblay, Shugrue, & Kline, 2006).

Arns, Kleinnijenhuis, Fallahpour, and Breteler (2007) demonstrated EEG profiles differed within participants when comparing made and missed golf putt trials, and these profiles also differed from person to person. Brain wave activity also appears to differ by skill level. Baumeister, Reinecke, Liesen, and Weiss (2008) collected EEG recordings in nine male golfers (mean age = 26.4 years, mean handicap = 8.3) and nine male novices (mean age = 24.6 years) while participants putted to a target 3 m away for 4 minutes. There were no differences in EEG measures at rest, but expert golfers performed better and showed different EEG profiles while putting compared to novices, leading the authors to believe experts had more efficient EEG profiles that aided their performance. Taking the performance context into account, Shelley-Tremblay et al. 2006 measured EEG activity and the reported mood of inexperienced golfers as they performed 20 golf putts with and without an audience. Participants showed decreased putting accuracy and increased beta wave activity (greater mental effort) when putting in front of an audience, but mood was not significantly affected. The researchers believed the presence of an audience increased arousal in performers, leading to increased effort, which they contended would be beneficial for experienced performers.

Research has demonstrated the important influence of cognitive activity on golf putting performance. However, most of these studies do not offer an explanation for how this knowledge can be used to improve putting performance or cope with stress in a competitive environment. Also, the use of EEG recordings during motor skill performance is intriguing and provides an interesting look at actual brain wave activity

during performance, but it is not a practical measurement method for many performance contexts. To address the issue of maintaining or improving skilled performance in a competitive environment, other research areas must also be considered.

### **Instruction in Golf Putting**

Putting is an essential skill in golf, and a multitude of instructional techniques have been introduced to aid performance. Malouff and Murphy (2006) tested the effects of self-instruction by dividing 77 men and 23 women (mean age = 41.8 years, mean handicap = 20) into control and intervention groups during an 18-hole putting tournament on a golf course practice green. Participants were further split into four age groups and told trophies would be awarded to the winners. After the first six holes the intervention group received specific self-instructions (e.g., “body still”) to think about while putting. Overall, the intervention group had better scores than control participants on the final 12 holes. However, the practical significance of this finding is questionable, as the difference between scores in the intervention and control participants was about one-half of a stroke over 12 holes. The authors were also unable to verify if these results would apply to elite athletes.

While self-instruction may be beneficial for golf putting performance, other research has suggested the use of mental imagery to improve performance in sport. Ploszay, Gentner, Skinner, and Wrisberg (2006) found a training program of multisensory imagery and simulated movements in a study involving two male and two female collegiate golfers produced inconclusive results. After a one-week intervention during which participants were instructed to act as if they were actually putting a golf ball using the approach they normally would on the putting green, participants reported that

they felt the imagery intervention helped, but actual putting performance was not significantly affected. Bell, Skinner, and Fisher (2009) employed solution-focused guided imagery intervention in a study involving three yips-affected male golfers (mean age = 51 years, handicap < 6). Following a maintenance phase of four to six weeks, the researchers found all three participants had decreased occurrences of the yips and decreased percentages of yips on short putts during the intervention and maintenance phases. Though these results support the use of mental imagery to treat the yips, no performance data was reported and the statistical power of the study is limited because of the small sample size.

While Ploszay et al. (2006) and Bell et al. (2009) found mixed results, Beilock and Gonso (2008) found imagery techniques did impact putting performance in 15 novice and 13 skilled (mean handicap = 5.8) undergraduate golfers. Participants were asked to perform multiple imagery tasks followed by putting tasks. During the mental imagery task, participants were instructed to imagine putting the ball to a target. Participants performed four blocks of 10 putts. In two of the blocks they were instructed to either putt or imagine putting as fast as possible while still being accurate, and in the other two blocks they were instructed to take as much time as necessary while using imagery or putting. Beilock and Gonso found skilled players were more accurate than novices overall, and novices were less accurate in the speed condition compared to the no-speed condition. Skilled participants were actually better in the speed putting condition and when following speed imagery, showing that experts and novices may be affected by mental imagery in different ways. This provides another example of how cognitive mechanisms can vary by skill level.

It remains unclear if self-instruction or mental imagery is truly beneficial for golf putting performance, but several studies have demonstrated that other instructional techniques can have detrimental effects on performance. De La Pena, Murray, and Janelle (2008) examined the phenomenon of implicit overcompensation using a golf putting task. In this phenomenon, instruction to not do a specific behavior results in overcompensation or a more extreme error in the other direction. For example, if a golfer is instructed to make a putt but to also be sure to not leave the putt short, they may actually overcompensate and putt the ball too far. In two separate experiments, they found overcompensation effects in both directions. Participants tended to putt the ball farther when instructed not to putt short, and to putt the ball shorter when instructed not to putt long, even though their primary goal was to land the ball on the target. Binsch, Oudejans, Bakker, and Savelsbergh (2009) found similar results. In a study involving 14 female and 13 male undergraduate novice golfers, they assessed performance during three separate putting conditions in which participants were instructed to either putt so the ball ended on a target, ended on the target but not short, or ended on the target but not long. While some participants showed good performance, others demonstrated either overcompensation or ironic effects, which occur when instruction to avoid a thought or action actually increases the tendency to engage in the thought or action. These results lead the authors to conclude negative instructions should be avoided when teaching tasks, which concurs with De La Pena et al.'s (2008) claim that it is more advantageous for participants to focus on what to do instead of what not to do.

The findings from De La Pena et al. (2008) and Binsch et al. (2009) demonstrate poor instruction may be harmful for relatively inexperienced golfers, but this may not

always be the case for highly skilled participants. Jenkins (2008) examined 15 elite professional golfers that normally relied on either wrist and hand movements or shoulder movements when putting. Using video recording and two expert judges to analyze the putting motion of the participants, He found that participants who normally used wrist and hand movements while putting couldn't prevent those movements when they were instructed to do so, and the same effect was found for participants who normally used shoulder movements. Jenkins concluded it was difficult to prevent the intrusion of movement habits in expert performers, but no claim was made as to which putting technique was superior because performance was not measured in this study. From this study, it would appear that instructions related to golf putting have a more significant impact on less experienced participants.

These studies provide insight into the complexity of the golf putting task and how golf putting performance relates to cognitive activity and instruction. However, a major concern for many golfers is the ability to putt successfully in a competitive environment when under pressure. Much of the research related to instruction in golf putting has not included a competitive environment. In following with the EC approach, the environment must be taken into account in order to understand how a competitive situation can affect golf putting performance.

### **Putting Under Pressure**

Researchers have employed a variety of methods to manipulate the competitive environment when studying golf putting. Previously mentioned studies by Mullen et al. (2005), Shelly-Tremblay (2006), Stinear et al. (2006), and Wilson et al. (2007) successfully manipulated competitive stress by introducing factors such as monetary

rewards based on performance, performing in front of an audience, or including a judge to critique performance. However, Stinear et al. (2006) and Wilson et al. (2007) did not find a significant effect of competitive stress on golf putting performance. A review of additional research in this area should provide a more complete understanding of the relationship between competitive stress and golf putting performance.

Putting performance in a competitive situation may be influenced by the performer's level of arousal. Murray and Raedeke (2008) defined arousal as a physiological response to real or perceived environmental demands that increase the activity of the sympathetic nervous system, and contended that large increases in arousal can result in muscle tension, distractibility, task irrelevant thoughts, changes in attentional focus, and poorer performance. They utilized HRV as a measure of arousal in 20 university students prior to performing golf putts in both a low and high pressure condition involving performing in front of an audience and the opportunity to earn extra credit. Participants had lower HRV and lower putting performance in the high pressure condition, which the authors attributed to increased arousal.

Anxiety is another common measure assessed in golf putting research, and Chamberlain and Hale (2007) suggested an athlete's perception of anxiety symptoms may help explain behavior. Their study involved 12 male golfers between the ages of 20 and 22 (mean handicap = 11.8) performing three separate putting sessions designed to manipulate anxiety (low, moderate, and high) through the use of monetary rewards. Each condition consisted of 10 putts to a target located 5 m away. Participants completed a competitive state anxiety survey before each task. A significant difference in anxiety was found between the three conditions, and the measured direction of anxiety was found to

be a more important predictor of performance than actual intensity of anxiety, supporting the original hypothesis of the importance of perception of anxiety. Though anxiety was successfully manipulated, no significant performance differences were found within participants across the three anxiety conditions. Tanaka and Sekiya (2010) found similar results in a study involving six male pro golfers and five male university students. After 10 blocks of 10 acquisition trials, participants were asked to putt in front of an audience of five people and were told they would win a cash prize if they improved on their performance from the acquisition phase. HR increased in all participants in the pressure condition, but state anxiety did not change. Both groups exhibited different kinematic movements during the putting motion in the pressure condition, but these changes did not influence performance and within-subject scores did not differ between the acquisition phase and high pressure condition.

While Chamberlain and Hale (2007) and Tanaka and Sekiya (2010) were unable to find a link between anxiety and putting performance, Cooke, Kavussanu, McIntyre, and Ring (2010) manipulated performance pressure in 23 male and 35 female novice golfers across multiple conditions and found fewer putts were made in the medium and high pressure conditions compared to the low pressure condition. Also, feelings of anxiety and effort, HR, forearm EMG activity, and lateral acceleration of the club were significantly higher in the high pressure condition. HRV was also higher in the high pressure condition compared to the low pressure condition, which was not expected. While these results are interesting, the difficulty of the putting task may limit their applicability to understanding putting performance, as participants putted to a target that

was one-half the size of a normal golf hole. This resulted in relatively low performance scores in all three rounds.

Researchers have been able to successfully manipulate the competitive environment to increase stress felt by participants in golf putting situations. In some cases, increased feelings of arousal or performance anxiety have influenced golf putting performance. Since a number of studies did not find a significant relationship between feelings of arousal or anxiety and performance, other measures must also be considered. While the research reviewed thus far has demonstrated cognitive processes and environmental factors play a role in motor skill performance, the EC approach also emphasizes the need to consider the bodily states of the performer as they are acting in the environment. It has been previously shown that brain wave activity (Arns et al., 2007; Baumeister et al., 2008; Shelley-Tremblay et al., 2006) and forearm muscle activation (Cooke et al., 2010; Smith et al., 2003; Stinear et al., 2006) are related to golf putting performance. However, each of these measures relies on equipment that would be difficult to utilize in a natural sporting environment.

Anderson (2005) suggested that when using EC theory, researchers should “look for ways that physiology is incorporated in, reflected by, evolved to better serve, or otherwise affects cognitive functioning” (p. 15). Cardiovascular responses such as HR and HRV have been successfully employed in multiple golf putting studies as indicators of arousal, attention, and anxiety. Another measure that has received less attention in golf putting and motor skill research in general is postural sway. The EC approach emphasizes the need to understand the action of the performer in the environment, and the nature of the golf putting motion lends itself to the measurement of both cardiovascular responses

and postural sway during the actual execution of the task. If the cognitive processes involved in motor skill performance are embodied, then measures such as cardiovascular responses and postural sway should be included to provide a more comprehensive understanding of golf putting performance in the context of a competitive environment. The next section discusses the relevance of these cardiovascular and postural sway measures and how they can be applied to golf putting research.

### **Heart Rate and Heart Rate Variability**

The measurement of HR has allowed researchers and clinicians to monitor health in a variety of situations. HR may seem like a relatively automatic, stable process, but it is actually a dynamic and complex process that is constantly modulated by sympathetic and parasympathetic influences of the nervous system. Sympathetic factors are designed to increase HR while parasympathetic influences decrease HR. The body's response to parasympathetic control is faster, but short lived, which typically leads to a higher degree of variation when vagal (parasympathetic) impulses are dominant. This higher degree of variation is believed to represent a normal, healthier system. HR is responsive to many factors including ventilation, blood pressure control, thermoregulation, and renin-angiotensin systems (Winsley, 2002). For example, HR generally increases during inspiration and decreases during expiration.

Since maintenance of HR is a dynamic and complex process, measures of HRV are commonly used to provide a more thorough understanding of HR modulation. HRV is defined as the temporal variation between sequences of consecutive heart beats and is typically measured in milliseconds. This variation can be recorded with the use of an ECG, which measures the electrical activity of the heart and can be used to determine the

maximum upward deflection of a normal QRS complex. This is referred to as the peak of the R wave, and the duration between two R wave peaks is called an R-R interval. HRV can then be interpreted as a measure of the balance between parasympathetic and sympathetic mediators of HR (Reed, Robertson, & Addison, 2005). Winsley (2002) also clarifies that HRV results from subtle modulation in parasympathetic and sympathetic tone, rather than the actual magnitude of tone.

Seely and Macklem (2004) suggest HRV measures are more valuable than HR alone, especially when HR is within normal limits. Physiological and pathological processes can influence HRV while HR may still appear normal. According to Reed et al. (2005), a variable HRV represents a normal physiological state and offers a survival advantage because the intrinsic variability of the system primes it to respond rapidly and appropriately to demands placed on it. Generally, people in good health have a relatively variable HRV, but this variability erodes with age or disease (Reed et al., 2005).

Measures of HRV are generally used in the medical field to aid in clinical diagnoses, but research involving HRV has extended to other fields. HRV has been associated with measures of attention (Porges & Byrne, 1992), as HRV tends to decrease when a person is paying more attention to a task. HRV is also said to be sensitive to variations in task complexity (Murray & Raedeker, 2008). For this reason HRV measures have been collected in subjects during activities such as rifle shooting and other shooting tasks (Augustin & Moravec, 2002; Saus et al., 2006; Zhuang et al., 2008) and previously mentioned studies on golf putting (Mullen et al., 2005; Murray & Raedeker, 2008; Wilson et al., 2007).

HRV data can be recorded using multiple methods. When trying to record HRV in participants while golf putting, the use of a noninvasive device to measure HRV would be beneficial. While HRV is usually measured with an ECG, telemetry devices such as heart rate monitors have been shown to be valid and reliable measures of HRV (Grossi Porto & Junqueira Jr., 2009; Nunan et al., 2009; Nunan et al., 2008). Heart rate monitors are relatively inexpensive, simple to use, and portable, making them an advantageous device for measuring HRV.

HRV represents a complex system, and numerous techniques have been developed to analyze HRV data. Seely and Macklem (2004) review some of the most common forms. Time domain analysis, the simplest form, studies variation over time in measures such as the standard deviations and ranges of data sets. These statistics are relatively easy to compute and can aid clinical diagnoses, but they do not reliably distinguish between distinct biological signals. In complex processes like HR modulation, multiple data series may have identical means and standard deviations but very different underlying rhythms. Another type of analysis is frequency domain or spectral analysis. This form converts time series data to a frequency domain, typically with a Fourier transformation. In this method, the amplitude of each sine and cosine wave determines its contribution to the biological signal. Frequency analysis, however, is limited by changes in posture and level of activity and is not able to compensate for variations that intrinsically arise from the dynamics of complex nonlinear systems such as HR modulation (Seely & Macklem, 2004). Since much of the research on golf putting performance has utilized frequency domain methods to analyze HRV data, the application of these findings may be limited.

HR modulation is an inherently variable complex process that can be influenced by many factors, including stress and anxiety. Increased stress is typically associated with greater sympathetic nervous system activity, and this increased sympathetic tone affects HR modulation. While parasympathetic tone increases HRV and generally represents a normal or healthy system, increased sympathetic tone is associated with higher arousal and decreased HRV, which may influence the performance of some motor skills. Due to the dynamic and complex nature of HR modulation, nonlinear methods have been introduced to gain a deeper understanding of this process.

Entropy analysis has emerged as a useful nonlinear method of HRV analysis. Entropy has been described as a measure of the rate of information production (Richman & Moorman, 2000) or as a measure of disorder or randomness (Seely & Macklem, 2004). Approximate entropy (ApEn) is a measure of the degree of regularity or randomness within a series of data, which is meant to provide a measure of system complexity. Smaller ApEn values represent greater regularity, while larger ApEn values represent more disorder, randomness, and system complexity. To determine entropy, the data series is evaluated for patterns that recur. Data sequences of a specified length are evaluated to help determine the likelihood that other runs of the same length in the data set are similar. This provides a measure of the underlying complexity of the system producing the dynamics (i.e., HR modulation). The clinical value of this technique is significant because complexity appears to decrease (HRV is reduced) in the presence of illness. Complexity also decreases with age as HRV tends to become less variable. Another advantage of entropy is its ability to be applied to short, noisy data sets that require about only 100-900 data points. Unlike time domain measures, ApEn requires the evaluation of

vectors representing consecutive data points, making the order of the data integral to its analysis. Also, significant noise or nonstationary data may compromise ApEn, so it should be used with other measures (Seely & Macklem, 2004).

Richman and Moorman (2000) claim nonlinear dynamical analysis could be a powerful approach for understanding biological systems and discuss the concept of entropy further. One limitation of ApEn is that its algorithm counts each sequence as matching itself. This bias makes ApEn heavily dependent on record length, as ApEn can be lower than expected for short records of data and it may over-report self-similarity. ApEn also lacks relative consistency. Due to these limitations, Richman and Moorman developed sample entropy (SampEn). Much like ApEn, SampEn can be applied to short, noisy data sets and provides an understanding of the nonlinear dynamics of complex systems. Unlike ApEn, SampEn doesn't count self matches and is largely independent of record length. It also displays relative consistency where ApEn does not. Porta et al. (2007) supported the claims of Richman and Moorman after measuring HR responses in participants during graded head-up tilt, which is associated with increased sympathetic modulation of HR. According to Porta et al., the bias resulting from the ApEn algorithm makes SampEn more appropriate for HRV analysis when using short recordings (about 220-260 heart beats in their study). Porta et al. also contend entropy measures are more appropriate for studying HRV than frequency domain analysis. Hautala et al. (2010) assessed HRV and physical activity in 21 male and 24 female healthy adults over a 24-hour period using a heart rate monitor with a built-in accelerometer, and determined SampEn had a high sensitivity to react to changes in physical activity at the individual level.

Biological systems such as HR modulation involve complex, dynamic processes. HRV has been established as a valuable tool for understanding the mechanisms of HR modulation and has been associated with various medical conditions as well as attention, arousal, and anxiety. HRV has also been measured in a number of golf putting studies. A wide range of techniques have been developed to better understand HRV, but the complex nature of this data calls for the use of nonlinear methods such as SampEn for HRV analysis. However, SampEn has not yet been used as a measure of HRV in studies related to motor skill performance. The inclusion of HRV analysis would aid research guided by EC theory, as it can be measured during skill performance and provides an indication of how the body is acting in the environment.

### **Postural Sway**

Stemm, Jacobson, and Royer (2006) claim proficiency in golf stems in part from appropriately timed and sequenced weight shift along with appropriate balance and stability. Hurrion (2009) contends that a golfer needs to have a stable, balanced, and solid base along with a fixed pivot point in order to execute the putting stroke consistently, and the inability to repeat these stroke mechanics under pressure would impair performance regardless of the golfer's ability to read the green. Though these claims highlight the importance of studying postural sway in golf putting, the role of postural sway has received relatively little attention in the golf putting literature.

The maintenance of upright stance may seem automatic, but research suggests standing posture requires a certain level of attention (Woollacott & Shumway-Cook, 2002). Since standing posture relies in part on central nervous system processing, it is often designated as a task in research involving measures of attention. During the

simultaneous performance of two tasks (dual-tasking), performance decrements in one or both tasks may occur. These decrements are often explained by the competition for limited central resources theory (Lajoie, Teasdale, Bard, & Fleury, 1993). According to this claim, the processing capacity of the central nervous system is limited, performing a task requires part of this limited capacity, and the performance of one or both tasks can be disturbed if the processing capacity they share is exceeded. Since both tasks are believed to require attention from the subject, the performance of one or both tasks could suffer if the demand of performing the two simultaneous tasks exceeds the attentional resources of the performer (Abernethy, 1988).

While research conducted in support of the competition for limited central resources theory has produced mixed results, other studies have generated results in direct opposition to the predictions of this theory. Riley, Baker, and Schmit (2003) found anterior-posterior sway significantly decreased as the difficulty of a digit rehearsal task increased, and sway variability did not change when trials containing errors were removed from analysis. They suggested releasing postural control from attentional focus and directing attention to a concurrent task may have allowed postural control to work in a more automatic and efficient manner. A subsequent study by Riley, Baker, Schmit, and Weaver, 2005 found medial-lateral sway variability decreased with increased cognitive load, which the authors contended was inconsistent with limited-capacity models of attention.

The role of vision has been shown to influence postural sway during task performance. Stoffregen, Bardy, Bonnet, and Pagulayan (2006), asked undergraduate participants to view either a stationary or moving target in an eyes-open condition. In an

eyes-closed condition, participants were asked to either not move their eyes or move them from side to side at a timed rate set to a metronome. Participants exhibited significantly less medial-lateral torso and head sway in the eyes-open moving target condition compared to the stationary eyes-open and moving eyes-closed conditions, as well as less anterior-posterior head and torso sway in the eyes-open moving target condition compared to the eyes-closed moving target condition. There were no significant sway differences when comparing the eyes-closed stationary and eyes-closed moving conditions. These results lead the authors to conclude the relationship between eye movements and postural sway was functional.

Stoffregen, Hove, Bardy, Riley, and Bonnet (2007) explored this idea further by comparing performance of perceptual and cognitive tasks while standing. They defined perceptual tasks as those that rely on some form of perceptual contact with the environment, while cognitive tasks do not. They found less anterior-posterior sway occurred while participants performed a signal detection (perceptual) task compared to a mental arithmetic (cognitive) task, even though both tasks had similar ratings of mental workload. A second experiment found no significant differences in postural sway when participants performed easy and difficult mental arithmetic tasks while standing. The authors proposed postural sway was not modulated to facilitate performance in the second experiment because a strictly cognitive task would not benefit from maintaining a specific relationship with the environment, and emphasized the need to distinguish between perceptual and cognitive tasks when using dual-task methodology.

These and similar results have lead some researchers to adopt an alternative view to the competition for limited central resources theory. Though decrements in one or both

tasks can be explained by a competition for limited central resources, this theory can not account for reduced sway (usually interpreted as improved balance) in dual-task situations (Riley et al., 2003), nor can it predict that the performance of either task will improve when they are performed simultaneously (Stoffregen et al., 2006). According to Riley et al. (2005), postural control requires the coordination of most muscle groups and appears to be guided by multiple perceptual systems, and cognitive load may constrain postural organization rather than reduce its effectiveness, which could account for either increases or decreases in postural stability.

Stoffregen et al. (2007) proposed a notion developed from the ecological approach to perception and action, which focuses on how perception and action are organized to allow animals to achieve behavioral goals. In this case, postural stance itself is neither considered a primary task nor considered to be maintained for its own sake. Instead, stance is integrated with other behaviors that are afforded during stance. Stoffregen et al. (2006) refer to these other behaviors as suprapostural tasks, which are tasks or behavioral goals that are subordinate to the control of posture. According to this view, posture is controlled to facilitate performance of suprapostural tasks that make demands on perceptual performance. In contrast to the limited central resources view, Stoffregen et al. (2006) contend posture and certain suprapostural activities could be integrated in such a way that their simultaneous performance would result in improved performance in one or both tasks.

Stoffregen et al. (2007) argue Woollacott & Shumway-Cook's (2002) definition of postural control is incomplete because it does not involve facilitation of suprapostural tasks. While some research has utilized postural sway variability as an index of postural

stability, this may not be a valid measure of postural stability. Postural stability implies the ability to maintain one's balance and prevent falling, but increased postural sway may not necessarily result in falls or the loss of balance, even if changes in postural sway measures are statistically significant. Postural sway variability should instead be assessed in the context of constraints imposed by suprapostural tasks (Stoffregen et al., 2006).

When studying postural sway, it is important to remember that it is a complex process that may be influenced by suprapostural tasks, as well as many other factors such as the surrounding environment, respiration, articulation, the act of listening, oculomotor demands, and the modality of a stimulus presentation (Kuczynski & Wieloch, 2008; Riley et al., 2005; Stoffregen et al., 2006; Stoffregen et al., 2007). These factors make postural sway variability a useful measure when considering EC theory. Many of the previously mentioned suprapostural tasks could be considered cognitive in nature, but they are often facilitated by the action of postural sway with respect to the environment.

Few studies have assessed the role of postural sway in golf putting. Stemm et al. (2006) found no differences in static or dynamic stability in 52 male golfers between the ages of 18 and 55 when they were split into three separate handicap groups, and suggested stability may be unique to each golfer and consistency of stability was more important than a specific number. This study has limited application, however, as simple balance tasks were used and no actual golf putting tasks were involved. Hurrion (2009) found a group of professional golfers had significantly more balanced left/right weight distribution and lower total COP movement when putting compared to a group of amateur golfers, though motion analysis showed no differences in kinematic measures such as stance width between the two groups. Hurrion believed the lower COP movement

exhibited by the professional golfers contributed to greater stability and balance during the putting stroke, and claimed all of the participants in the study were capable of obtaining a more stable and balanced position for the putting stroke. However, the relationship between COP movement and performance was not directly assessed in this study, as no measures of putting performance were provided.

Head motion can also influence postural sway. Lee, Ishikura, Kegel, Gonzalez, and Passmore (2008) argued that the ability to keep the head completely motionless during the putting stroke was a unique coordination constraint that must be learned, and that performers should separate motion of the head from motion of the upper body and the putting club. They found less experienced golfers moved their head in the same direction as the club during the putting motion, but surprisingly, the opposite effect was demonstrated by the expert golfers. Contrary to the authors' hypothesis that experts would not exhibit head motion, expert golfers moved their head in the opposite direction of the putter during the putting stroke. Lee et al. proposed the backswing phase of the putting motion may perturb the postural equilibrium established prior to putting, and the opposite motion of the head while putting may serve to counteract the perturbation. The authors suggested specific practice involving feedback could lead to a putting motion characterized by a motionless head during the putt.

Hurrion's (2009) claim that all golfers could obtain a more balanced and stable position to aid the putting stroke and Lee et al.'s (2008) expectation of a motionless head during the putt may both be unreasonable. As discussed earlier, postural sway is not necessarily a measure of postural stability, and constraints imposed by suprapostural tasks must be taken into account (Stoffregen et al., 2006). Postural sway and head motion

during the putting stroke may differ between performers of different ability levels, but it is unlikely that any performer would exhibit postural motion that is perfectly still or perfectly balanced. As long as postural motion is maintained within an appropriate range, golf putting and other perceptual motor tasks should still be able to be performed at a high level. What should be of concern is how the competitive environment influences postural sway, and whether this has an effect on performance. Research has demonstrated postural sway's role in the facilitation of suprapostural tasks, but little attention has been paid to this subject in studies of motor skill performance.

### **Comparing Novices and Experts**

When studying the learning and performance of motor skills, it is important to consider performers of varying levels of ability and experience. In a review of research pertaining to novice and expert performance, Beilock and Carr (2004) claim cognitive control structures that support planning and lead to execution distinguish novice from expert performance. Motor skill performance relies on particular forms of memory and attentional demands, both of which change as practice accumulates and skill proficiency increases. Previously mentioned research on golf putting has demonstrated that aside from actual putting performance, expert and novice golfers also differ in measures of attention (Beilock et al., 2002), brain wave activity (Baumeister et al., 2008), use of mental imagery (Beilock & Gonso, 2008), and HRV (Neumann & Thomas, 2009) while putting. In addition, Naito, Kato, and Fukuda (2004) recorded eye movements of golfers of varying levels of experience while putting and found significant differences in fixation points when comparing expert, intermediate, and beginning golfers.

Researchers have also found differences in kinematic variables related to the putting motion when comparing golfers of varying experience (Delay et al., 1997; Hurrion, 2009; Lee et al., 2008; Tanaka & Sekiya, 2010). Sim and Kim (2010) further explored this area in a motion analysis study comparing the backswing, downswing, and follow-through phases of the putting motion in five expert and five novice golfers. The researchers found expert performers had longer backswing and follow-through durations and shorter downswing durations compared to novices, displaying a difference in the relative timing of the skill between the groups. Sim and Kim also found experts and novices exhibited different club trajectories and amplitudes during the putting motion, and concluded that while a fundamental property of a motor skill may remain unchanged, some properties of the skill may vary depending on the level of expertise.

Many variables have been used to explore the differences between expert and novice performers. Since motor learning depends heavily on practice and experience, it is important to apply this knowledge to help understand how performance can be enhanced. Researchers have identified a number of important differences between golfers of varying levels of experience, leading to a better understanding of the skill of golf putting. These differences highlight the need to consider performers across all ranges of ability when studying golf putting performance.

### **Summary**

While many research studies have utilized the task of golf putting for an array of purposes, few of them have focused on the relationship between aspects of the performer and the competitive environment in golfers of varying levels of experience. Some studies have simply used the golf putting task to assess dual-task performance, and many of them

have only included participants with no prior golfing experience (Binsch et al., 2009; De La Pena et al., 2008; Ishikura, 2008; Mullen, Hardy, & Oldham, 2007; Poolton, Maxwell, Masters, & Raab, 2006; Shelley-Tremblay et al., 2006). Studies have also asked participants to perform simultaneous tasks that are irrelevant to the task of golf putting (Beilock et al., 2002; Binsch et al., 2009; De La Pena et al., 2008; Mullen et al., 2005). These efforts may be beneficial for explanations regarding theories of learning and attention, but they provide no helpful evidence for golfers with impaired putting performance in competitive situations.

Past research has been hindered by other limitations as well. Even though the yips typically occur during relatively easy short putts that are 5 feet or closer to the hole, many studies have included putting distances well beyond that range (Baumeister et al., 2008; Chamberlain & Hale, 2007; Malouff & Murphy, 2006; Marquardt, 2009; Mullen et al., 2005; Neumann & Thomas, 2009; Ploszay et al., 2006; Stinear et al., 2006; Tanaka & Sekiya, 2010; Wilson et al., 2007). These longer distances may have added undue difficulty to the task and limited the ability to truly understand the relationship between various stimuli and golf putting performance.

A number of studies have also asked participants to putt to a marked target instead of an actual golf hole (Baumeister et al., 2008; Beilock & Gonso, 2008; Beilock et al., 2002; Binsch et al., 2009; Chamberlain & Hale, 2007; De La Pena et al., 2008; Delay et al., 1997; Tanaka & Sekiya, 2010). In some cases this may have aided the specific design of the study, but the fundamental goal of the task was changed. Putting to a golf hole involves a larger margin of error than putting to a flat target of the same size. Every putt that lands on a target would also have gone into a golf hole, but not every putt that sinks

into a golf hole would land and stay on a target. Golf balls traveling at different speeds can still find the hole, but golf balls traveling at higher speeds may land beyond the target. This added difficulty may not be ecologically valid, as scoring in golf is determined by putting into a hole, not putting onto a target.

Advances in technology have allowed researchers to assess more variables during performance of a motor task. Several studies (Mullen et al., 2005; Neumann & Thomas, 2009; Wilson et al., 2007) have utilized HRV frequency domain analysis as a measure of attention in participants while golf putting. HRV may also be interpreted in terms of anxiety or arousal (Murray & Raedeke, 2008), but this has rarely been addressed in previous golf putting studies. While these findings are useful, recent research has suggested frequency domain analysis may not be the most appropriate method for describing short, noisy data sets of dynamic, complex biological systems like HR modulation (Porta et al., 2007; Richman & Moorman, 2000; Seely & Macklem, 2004). With this in mind, nonlinear techniques such as SampEn would be beneficial for HRV analysis in golf putting research.

Postural sway has been shown to facilitate the performance of suprapostural tasks (Stoffregen et al., 2006; Stoffregen et al., 2007), but only one study (Hurrion, 2009) has specifically examined postural sway during the golf putting motion. Appropriate coordination of postural sway is necessary for successful golf putting, but the association between postural sway and putting performance has not yet been studied. Further research in this area would help explain how golfers are affected by a competitive environment while putting.

Millions of people enjoy the game of golf, but the occurrence of the yips can impair performance and decrease enjoyment of the game. Since this condition is prevalent in experienced golfers, directed research is needed to specifically address the problem. The yips appear to be a multifaceted problem for many golfers, and research in this area must consider multiple factors in order to understand this phenomenon. Using the EC approach, a wide range of factors concerning cognitive activity and the relationship between the performer and the environment can be assessed. Since previous golf putting research has demonstrated the importance of all of these factors, a study guided by EC theory would greatly benefit further understanding of golf putting performance in a competitive environment. An increased awareness of the many mechanisms involved in competitive golf putting will aid future research in the hopes of treating or preventing the occurrence of the yips in golf.

### **III. Methodology**

The purpose of this study was to measure postural sway, HR, and HRV in both experienced and inexperienced participants in competitive golf putting environments. This research was guided by EC theory and addressed the question of whether postural sway, HR, and HRV change as a function of competitive setting in golf putting, and how these changes might affect performance. It was hypothesized that a more competitive environment would lead to reduced postural sway variability, increased HR, and reduced HRV variability. Lower values of postural sway variability and HRV were also expected to correlate with better putting performance. A pilot study was conducted, followed by two separate experiments that both utilized a repeated measures design. A competitive environment was created through the use of a tournament format along with the opportunity to win a monetary reward while performing in front of an audience in both experiments, which has been shown to be a successful method for inducing competitive stress (Chamberlain & Hale, 2007; Cooke et al., 2010; Mullen et al., 2005; Stinear et al., 2006; Tanaka & Sekiya, 2010; Wilson et al., 2007).

#### **Pilot Study**

The pilot study was conducted to test the feasibility of collecting postural sway and HR data in participants while they attempted golf putts. Six male ( $23.5 \pm 3.5$  years) and five female ( $25.6 \pm 5.6$  years) University of Minnesota students participated in the pilot study. All participants were inexperienced golfers. Pilot testing was completed in an indoor laboratory setting using a custom made putting platform. The platform measured 3 feet by 7 feet (0.91 m by 2.13 m) and had a carpeted surface to simulate a putting green. The platform was about 2 in (5.1 cm) high, which was the same height as a force plate

that was placed adjacent to the putting platform. This allowed participants to stand on the force plate while putting a golf ball located on the platform. The force plate was connected to a personal computer, which recorded postural sway data in real time. Participants putted a golf ball to a hole in the platform located 5 feet (1.52 m) away. The hole had a circumference of 4 in (10.16 cm), which is slightly smaller than a regulation-size golf hole (4.25 in or about 10.80 cm).

Prior to testing, participants were informed of the purpose of the pilot study and provided consent. Before attempting any putts, participants were asked to stand on the force plate for two minutes while wearing a heart rate monitor (Polar RS800), which is a HR telemetry device consisting of a chest strap and wristwatch worn by the participant. The chest strap is worn on the skin and detects heart beat signals, which are simultaneously recorded by the wristwatch. Data recorded on the wristwatch can later be transferred to a personal computer for analysis. During this time, participants were asked to adopt a normal stance with their arms at their side while looking straight ahead, and were instructed to refrain from talking. Postural sway data were recorded for one minute, and HR data were collected for two minutes.

After the baseline measures of HR and postural sway were recorded, participants were allowed three practice putts. They then performed 15 additional putts, during which postural sway and HR were recorded. Postural sway was recorded for each putt and began once the participant had become set to hit the ball. Once the participant appeared set, the researcher provided a “go” signal. Participants were instructed to putt the ball after receiving the signal, but were encouraged to initiate and perform the putting motion at their own pace. Postural sway data were recorded from the initiation of the “go” signal

until the putter made contact with the ball. HR data were recorded continuously throughout the 15 putts. The putter and ball were provided by the researcher. After completion of the pilot study, it was determined that postural sway and HR data could be measured simultaneously while participants attempted golf putts. Several changes were made to the testing protocol and are discussed in detail later.

## **Experiment 1 – Field Study**

### **Participants**

This experiment measured HR, HRV, postural sway variability, and putting performance of experienced golfers in a competitive setting through the use of a tournament format in a repeated measures design. Nineteen members of the University of Minnesota Men's Golf Club ( $51.4 \pm 17.5$  years, handicap =  $11.6 \pm 5.3$ ) participated in the study. All participants were active golfers and did not report any health issues. Participants were recruited at the course after competing in golf events, and were informed they would receive a \$5 gift card for participating in the study. In order to foster a competitive environment, they were also told the winner would be awarded a \$100 gift card. Of the 19 participants that completed the first round, 15 of them completed the second round and 7 of them competed in the final round. Participants provided informed consent (Appendix A) before beginning the study, and procedures were approved by the University of Minnesota's Institutional Review Board.

## **Measurements**

### ***Postural Sway***

A Wii balance board (Nintendo, Kyoto, Japan) was used as a force plate and transmitted postural sway data to a laptop computer equipped with a software program (NeuroEx) to collect and analyze the data. The Wii balance board has been shown to be a valid and reliable instrument for measuring postural sway (Clark et al., 2009), and is an inexpensive and more portable alternative to force plates. Postural sway was recorded from the onset of a “go” signal until the putter made contact with the ball for each trial. Postural sway data were recorded in real time using a personal computer that was wirelessly connected to the balance board, and were sampled at a rate of 32 Hz. These data were later analyzed using NeuroEx software, and postural sway was expressed as the standard deviation of the COP movement in both the medial-lateral (ML) and anterior-posterior (AP) axes, a method employed by Stoffregen et al. (2006) and Stoffregen et al. (2007). The time between the provision of the “go” signal and the point where the putter made contact with the ball was also recorded, and was expressed as putting time.

### ***HR and HRV***

HR data were collected using a Polar RS800 heart rate monitor, which consists of a chest strap and wristwatch. These devices are noninvasive and provide a valid and reliable measure of HR and HRV. HR data were continuously collected throughout each round (session). Data stored on the wristwatch were later transferred to a personal computer using Polar software and further processed using Kubios software (Tarvainen & Niskanen, 2008). Using this software, HR was expressed as the average number of beats per minute (bpm), and HRV was expressed as SampEn.

### ***Putting Performance***

Putting performance was measured after each attempt and was expressed as the distance of the ball from the hole once it came to a stop. The hole had a diameter of 4.25 in (10.80 cm). Successful putts were recorded as 0 cm. This method has been used in previous studies (Cooke et al., 2010; Wilson et al., 2007) and is meant to provide a more precise measure of putting accuracy than recording the number of putts made. Once the distance was measured, the ball was placed back at the original putting distance (6 feet in the first two rounds, 8 feet in the final round) for the next attempt. All measurements were performed by the researcher.

### **Procedures**

All testing took place at the University of Minnesota Les Bolstad Golf Course practice putting greens. Participants were asked to perform two to three rounds of golf putts in a tournament style format. Baseline measures of postural sway and HR were collected before the first and second rounds. During this time, participants were asked to adopt a normal stance with their arms at their side while facing forward and instructed to refrain from talking. Postural sway was recorded for 1 min and HR was recorded for 2 min. Participants were then allowed three practice putts while standing on the balance board before each round. Each participant used his own putter and golf ball. Participants typically completed each of the first two rounds in 10 to 15 min. Since the final round involved a group of participants performing at the same time, more time was required for this round. Baseline measures of postural sway and HR were not recorded before the third round due to time constraints.

The first round was a practice round in which scores did not count. Participants completed 15 flat putts at a distance of 6 feet (1.83 m) from the hole. This distance was chosen because it was believed that the shorter distance used in the pilot study would have been too easy for skilled golfers. Several weeks after the first round, participants completed a second round of 15 putts from the same distance, but this time participants were made aware that their scores would count and the best performers would move on to a final round to determine a winner. They were also reminded that a \$100 gift card would be awarded to the winner. In the first two rounds, participants performed without an audience. In the final round, they performed in front of the other six finalists.

The final round was completed in one day and utilized a knockout format, in which participants performed five putts from a distance of 8 feet (2.44 m). A longer distance was used in the final round in an attempt to increase difficulty and place more stress on the participants. The final round started with seven finalists. After each participant performed five putts, the top four performers moved onto the next round and performed five more putts. The top two scorers from that round then attempted five more putts to determine the winner. In the event of a tie, participants were asked to attempt three more putts. The final round lasted about two hours. Participants were compensated at the conclusion of the experiment. The first place winner received a \$100 gift card, the second place winner received a \$50 gift card, and the other finalists received \$10 gift cards. All other participants received \$5 gift cards.

### Statistical Analysis

Several preliminary statistical procedures were computed. All data were examined using Shapiro-Wilk tests and Q-Q plots to confirm they met the normality assumption for applicable statistical tests. Also, preliminary analysis of postural sway data was carried out to determine if there were any within-subjects differences when comparing putts made and putts missed. Average values were computed for each participant in each of the first two rounds for both made and missed putts, resulting in two separate postural sway measures (made and missed) for both the ML and AP axes. Since there were fewer participants in the final round and some of them did not successfully hole any putts, made and missed putts from Round 3 were not included in this analysis. Paired t-tests displayed no differences in postural sway variability when comparing made and missed putts within subjects in Round 1 for both ML sway [ $t(18) = 0.25$ ,  $p = .80$ ] and AP sway [ $t(18) = -0.80$ ,  $p = .44$ ]. Likewise, there were no differences in postural sway variability when comparing made and missed putts within subjects in Round 2 for both ML sway [ $t(13) = -0.16$ ,  $p = .88$ ] and AP sway [ $t(13) = 0.23$ ,  $p = .82$ ]. For this reason, postural sway data were calculated for each participant as the average of all putting trials within each round for both the ML and AP axes.

To determine the effects of performing in a more competitive environment, paired t-tests were computed to compare measures within participants between Round 1 and Round 2. Putting performance, putting time, and measures of ML sway, AP sway, HR, and HRV recorded both prior to and during performance were included as dependent variables. A series of repeated measures analysis of variance (RM ANOVA) tests were also performed to assess changes in putting performance, putting time, ML sway, AP

sway, HR, and HRV during performance within subjects that participated in all three rounds. Since baseline measures of postural sway, HR, and HRV were not recorded prior to Round 3, these variables were not compared across all three rounds. Pearson correlation coefficients were calculated to determine the magnitude of the associations between all variables measured prior to and during performance for all participants in each round. Statistical tests were computed using SPSS 19.

Hypothesis tests were considered significant at the  $p < .05$  level. Additionally, the magnitude of the differences in means was shown as effect size  $d = (m_2 - m_1)/s_{\text{pooled}}$ , where  $m_1$  and  $m_2$  are the means of the two groups or treatments and  $s_{\text{pooled}}$  is the pooled standard deviation calculated as the square root of  $[(n_2 - 1)s_2^2 + (n_1 - 1)s_1^2]/n_1 + n_2 - 2$ , where  $n$  is sample size and  $s^2$  is variance (Nakagawa & Cuthill, 2007). Effect sizes and Pearson correlation coefficients were interpreted according to the criteria used by Cohen (1988):  $<0.2$  = trivial,  $0.2-0.4$  = small,  $0.5-0.7$  = moderate,  $>0.7$  = large.

## **Experiment 2 – Laboratory Study**

Experiment 2 was designed after Experiment 1 was concluded. The same measures were collected during performance and a similar experimental protocol (three-round tournament) was employed. However, based on the results found in Experiment 1, limitations identified in Experiment 1, and findings from earlier research, several changes were made to the design for Experiment 2. The putting task was slightly altered by including two different putting distances. Also, Experiment 2 was conducted in an indoor facility, an additional measure of arousal was included, and participants were not experienced golfers. The rationale for these changes is provided in the following sections.

## **Participants**

Ten male ( $20.6 \pm 1.1$  years) and 10 female ( $24.2 \pm 7.1$  years) University of Minnesota students participated in Experiment 2. Participants were recruited from several kinesiology department classes and were told they would receive monetary compensation for participation along with the chance to win additional money if they advanced to the final round. They were also informed that study participants could not be experienced golfers. All participants reported that they were not members of a golf team or club and were not experienced golfers. Participants reported no health issues that would have interfered with their ability to perform the putting tasks, and gave consent prior to participating. Procedures were approved by the University of Minnesota's Institutional Review Board.

## **Measurements**

Postural sway, HR, HRV, and putting performance were recorded during each round using the same methods and equipment from Experiment 1. The putting task was altered, as participants were asked to perform putts from two different distances (3.5 feet and 5.5 feet) in each round (see Appendix B). This change was made to introduce putting tasks of different difficulty within each session. A lap marker on the heart rate monitor was used to differentiate between long and short putting trials, resulting in separate HR and HRV values for both putting conditions within each round. Baseline measures of postural sway (1 min) and HR (2 min) were also recorded before each round.

To provide an additional measure of arousal, participants were asked to complete a slightly modified version of the Sport Grid-Revised (SGR) after baseline measures of postural sway and HR were recorded. The SGR (see Appendix C) was developed by

Ward and Cox (2004) to provide a short and simple scale that would allow researchers to quickly measure anxiety and arousal as close to actual performance as possible. The SGR measures two constructs, cognitive anxiety and felt arousal. These measures are placed on a nine-by-nine grid which asks participants to indicate both their degree of felt arousal along with their cognitive anxiety about an upcoming event. By placing an “X” in the grid, participants provide a simultaneous measure of both constructs, which are each graded on a 9-point scale. The organization of the instrument allows participants to make a fast judgment of their current arousal and anxiety levels. Though the original version of the SGR reminds participants to indicate their degree of worry about their individual performance and not their team’s performance, the reference to team performance was removed from the SGR for the current study to avoid confusion.

### **Procedures**

This experiment followed a similar protocol to Experiment 1, but several changes were made to address limitations discovered after the first experiment. Experienced golfers participated in Experiment 1. To enable comparisons between participants of different ability, inexperienced golfers participated in Experiment 2. Due to considerations about time and weather conditions, Experiment 2 was conducted in an indoor laboratory facility using the golf putting platform described in the pilot study. In each round, participants were asked to perform five long putts (5.5 feet or 1.67 m) followed by five short putts (3.5 feet or 1.07 m). This change was made in an attempt to include tasks of unequal difficulty, and fewer overall putts were used to reduce the chance of a learning effect. Participants were allowed two practice putts from the longer distance before attempting the 10 putts. Whereas the final round in Experiment 1

involved a more difficult putting task than the earlier rounds, having participants perform the same putting tasks in all three rounds in Experiment 2 allowed for easier comparison of variables across rounds. A putter and golf ball were provided by the researcher.

This experiment also employed a three-round tournament that included the chance to win a monetary reward to foster a competitive environment. All 20 participants completed the first two rounds. Once again, the scores in the first round did not count. In the second round, participants were reminded that their scores would count and the best performers would move on to the next round for a chance to win more money. Also, participants performed in groups of four to six in the second round. This change was enacted to create a more competitive environment through the use of a small audience. The top eight performers from the second round advanced to the third and final round. This round included two separate sessions, each of which involved a group of four participants. From each group of four, one winner was determined. In the event of a tie, participants were asked to perform two putts from each distance. Each of the winners from the two final groups received a \$75 gift card, and the other finalists received \$25 gift cards. Participants that did not reach the final round received \$10 gift cards. All participants received their compensation at the conclusion of the study.

### **Statistical Analysis**

The same preliminary analysis described in Experiment 1 was also applied in Experiment 2. Once again, normality assumptions were met. There were no significant differences in ML sway in Round 1 when comparing made and missed putts within participants in both the long putt [ $t(18) = 1.80, p = .09$ ] and short putt [ $t(19) = 1.00, p =$

.33] conditions, nor were there significant differences in AP sway in Round 1 when comparing made and missed putts in both the long putt [ $t(18) = -1.01, p = .33$ ] and short putt [ $t(19) = 1.80, p = .09$ ] conditions. In Round 2, there were no significant differences in ML sway when comparing made and missed putts in both the long putt [ $t(17) = 2.01, p = .06$ ] and short putt [ $t(9) = -0.61, p = .56$ ] conditions, and no differences when comparing AP sway during made and missed putts in both the long putt [ $t(17) = 1.20, p = .25$ ] and short putt [ $t(9) = 1.18, p = .27$ ] conditions. As a result, postural sway data were calculated for each participant as the average of all putting trials for each condition (long and short) within each round for both the ML and AP axes.

To determine if dependent variables differed significantly within participants between Round 1 and Round 2, a 2 x 2 (Round x Putting Condition) RM ANOVA was computed using putting performance, postural sway, putting time, HR, and HRV while putting as dependent variables. Paired t-tests were employed to compare preperformance (baseline) measures of ML sway, AP sway, HR, and HRV within subjects in the first two rounds. Since the scores from the SGR did not constitute continuous data, Wilcoxon signed rank tests were used to compare the distribution of the *Worry* and *Activation* scores from the SGR between Round 1 and Round 2 in all participants. Also, a 3 x 2 (Round x Putting Task) RM ANOVA was computed to assess changes in putting performance, ML sway, AP sway, putting time, HR, and HRV while putting within subjects that participated in all three rounds, and a series of RM ANOVAs was used to measure changes in preperformance measures of ML sway, AP sway, HR, HRV, *Worry*, and *Activation* within participants across all three rounds.

Pearson correlation coefficients were calculated to determine the magnitude of the associations between all variables measured prior to and during performance for all participants in each round, and effect sizes were calculated to represent the magnitude of the differences in means. Pearson correlation coefficients and effect sizes were again interpreted according to the criteria used by Cohen (1988):  $<0.2$  = trivial,  $0.2-0.4$  = small,  $0.5-0.7$  = moderate,  $>0.7$  = large. Statistical tests were computed using SPSS 19 and were considered significant at the  $p < .05$  level.

## IV. Results and Discussion

The central question of the present research asked if postural sway variability, HR, and HRV change as a function of competitive setting in golf putting, and how these changes affect performance. It was hypothesized that a more competitive setting would result in decreased postural sway variability, increased HR, and decreased HRV, and that lower values of postural sway variability and HRV would be associated with better putting performance. Statistical tests yielded a number of significant findings related to putting performance, postural sway, HR, HRV, and ratings of perceived worry and activation.

### Experiment 1 Results

Abbreviations for dependent variables are listed in Appendix D. Within-subject comparisons of putting performance and putting time are displayed in Figures 1 and 2 and Appendix D. Within-subject comparisons of postural sway, HR, and HRV between Round 1 and Round 2 are shown in Table 1, and within-subject comparisons of these variables measured during performance across all three rounds are displayed in Table 2a. The RM ANOVA concerning changes in HR across all three rounds was significant, and follow-up pairwise comparisons were computed to assess the differences in HR between each of the three rounds (see Table 2b). Pearson correlation coefficients between dependent variables for all participants in Round 1 and 2 are provided in Table 3, and for Round 3 participants in Appendix D. Results are described further in the following sections.

Regarding putting performance, a paired t-test showed mean putting error was not significantly different within subjects between Round 1 and Round 2,  $t(14) = 0.49$ ,  $p =$

.63. An RM ANOVA showed a significant difference in putting performance across Rounds 1-3,  $F(2, 12) = 16.89$ ,  $p = .00$ , and pairwise comparisons were computed to measure the differences in putting performance between each round for the final round participants. In this case, participants performed worse in Round 3 compared to Rounds 1 and 2 (see Figure 1 and Appendix D). Putting time was significantly shorter within all subjects in Round 2 compared to Round 1,  $t(13) = 2.42$ ,  $p = .03$ , but no within-subjects effect was found when assessing putting time in participants that completed all three rounds,  $F(2, 10) = 2.08$ ,  $p = .18$  (see Figure 2 and Appendix D).

Figure 1. Putting Performance in Experiment 1

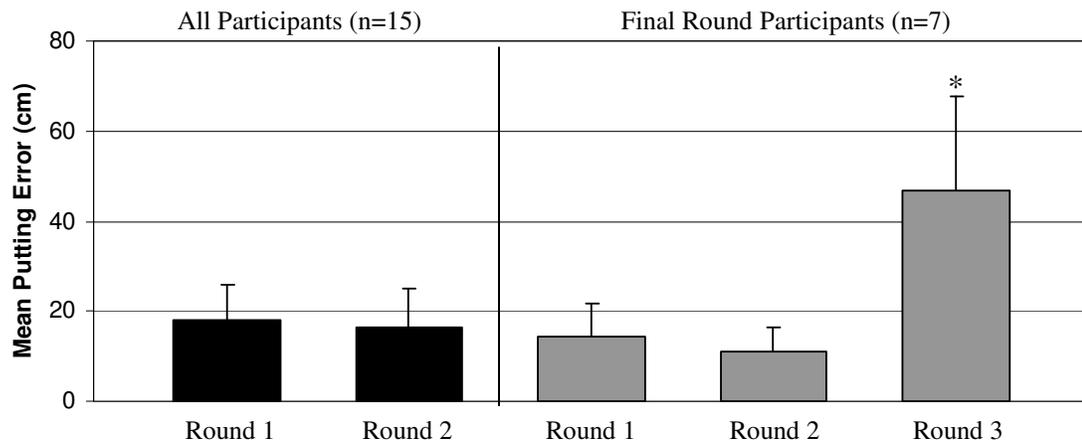


Figure 1. Putting performance in Rounds 1 and 2 and Across Rounds 1, 2, and 3 in Experiment 1. Bars represent group means, error bars represent standard deviations.

\* Significant difference in mean putting error across rounds for final round participants

Figure 2. Putting Time in Experiment 1

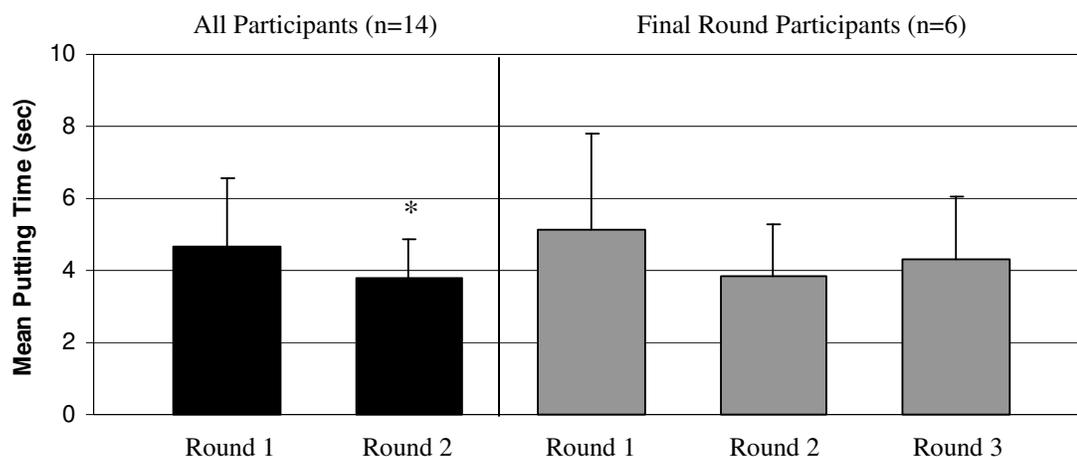


Figure 2. Putting time in Rounds 1 and 2 and Across Rounds 1, 2, and 3 in Experiment 1. Bars represent group means, error bars represent standard deviations.

\* Significant difference in mean putting time between Rounds 1 and 2 for all participants

Note. Putting time data were unavailable for one participant that completed all three rounds.

### **Hypothesis 1 – Postural sway variability will decrease in a more competitive condition**

Paired t-tests showed no significant differences in ML sway variability when comparing normal stance within subjects between Rounds 1 and 2, and the same result was found for AP sway variability (see Table 1). ML sway variability while putting also did not differ within subjects between the first two rounds. However, participants showed significantly less AP sway variability while putting in Round 2 compared to Round 1, and this was associated with a large effect size (see Table 1 and Figure 3). RM ANOVAs showed no significant changes in ML or AP sway variability during performance within participants that completed all three rounds (see Table 2a).

Table 1

*Within-subject Comparisons in Rounds 1 and 2 in Experiment 1*

Measure	n <sup>†</sup>	Round 1 Mean (SD)	Round 2 Mean (SD)	t (df)	p	Effect Size <i>d</i>
MLPre	14	0.32 (0.29)	0.18 (0.07)	2.03 (13)	.06	0.66
APPre	14	1.34 (0.32)	1.29 (0.33)	0.61 (13)	.55	0.15
HRPre	14	93.0 (17.0)	88.5 (14.3)	1.37 (13)	.19	0.29
HRVPre	14	1.00 (0.17)	1.03 (0.37)	-0.34 (13)	.74	-0.10
MLPutt	14	0.75 (0.65)	0.57 (0.28)	0.97 (13)	.35	0.36
APPutt	14	1.53 (0.51)	1.18 (0.34)	2.44 (13)	.03*	0.81
HRPutt	15	98.1 (15.4)	96.0 (12.5)	0.96 (14)	.36	0.15
HRVPutt	15	0.75 (0.29)	0.78 (0.27)	-.51 (14)	.62	-0.11

\* p &lt; .05

† One case was excluded in several of the paired t-tests because baseline HR and HRV data were unavailable for one participant in Round 1, and postural sway measures were unavailable for one participant in Round 2

Figure 3. Postural Sway in Rounds 1 and 2 in Experiment 1

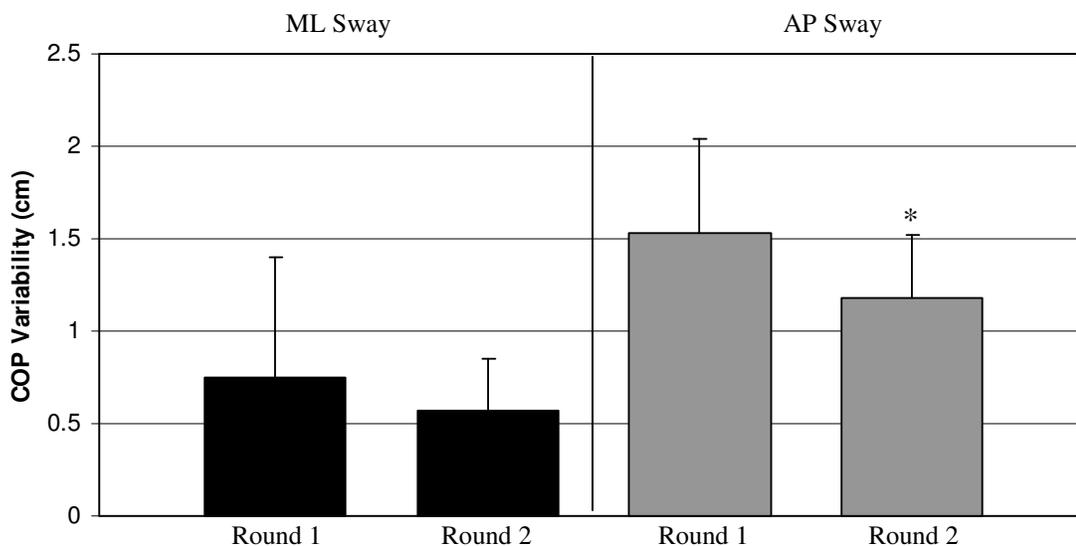


Figure 3. Mean ML and AP postural sway variability in participants (n =14) in Rounds 1 and 2 of Experiment 1. Bars represent group means, error bars represent standard deviations.

Note. Postural sway data were unavailable for 1 of the 15 participants that completed both rounds.

\* Significant difference in AP sway between Round 1 and Round 2 within subjects

### **Hypotheses 2 and 3 - HR will increase and HRV will decrease in a more competitive condition**

When comparing Round 1 and Round 2, paired t-tests showed no significant within-subject differences in either HR or HRV during normal stance or while putting (see Table 1). However, an RM ANOVA showed a significant difference in HR in participants that completed all three rounds (see Table 2a and Figure 4). Though HR measures were higher in Round 3, follow-up pairwise comparisons using a Bonferroni correction ( $p = .05/3 = .017$ ) did not reach statistical significance. However, large effect sizes demonstrated an increase in HR while putting during Round 3 compared to both

Rounds 1 and 2 (see Table 2b). HRV while putting did not significantly differ within subjects that participated in all three rounds (see Table 2a and Figure 4).

Table 2

*a) Within-subject Comparisons Across Rounds 1, 2, and 3 in Experiment 1*

Measure	n <sup>†</sup>	Round 1 Mean (SD)	Round 2 Mean (SD)	Round 3 Mean (SD)	F (df)	p
MLPutt	6	0.79 (0.92)	0.48 (0.17)	0.65 (0.51)	0.69 (2, 10)	.52
APPutt	6	1.38 (0.52)	0.95 (0.22)	1.19 (0.44)	1.91 (2, 10)	.20
HRPutt	7	99.5 (13.3)	98.1 (9.3)	112.7 (8.5)	6.21 (2, 12)	.01*
HRVPutt	7	0.69 (0.23)	0.70 (0.26)	0.62 (0.23)	0.72 (2, 12)	.51

\*  $p < .05$

† One case was excluded in several of the RM ANOVAs because postural sway measures were unavailable for one participant in Round 2

*b) Pairwise Comparisons of HR Across Rounds 1, 2, and 3 in Experiment 1*

Measure	Rounds	Mean (SD)	p	Effect Size <i>d</i>
HRPutt	1, 2	99.5 (13.3), 98.1 (9.3)	1.000	0.12
n = 7	1, 3	99.5 (13.3), 112.7 (8.5)	.185	-1.18
	2, 3	98.1 (9.3), 112.7 (8.5)	.056	-1.64

Note. Statistical significance if  $p < .017$  (Bonferroni adjustment,  $.05/3$ ).

Figure 4. HR and HRV in Final Round Participants Across Rounds in Experiment 1

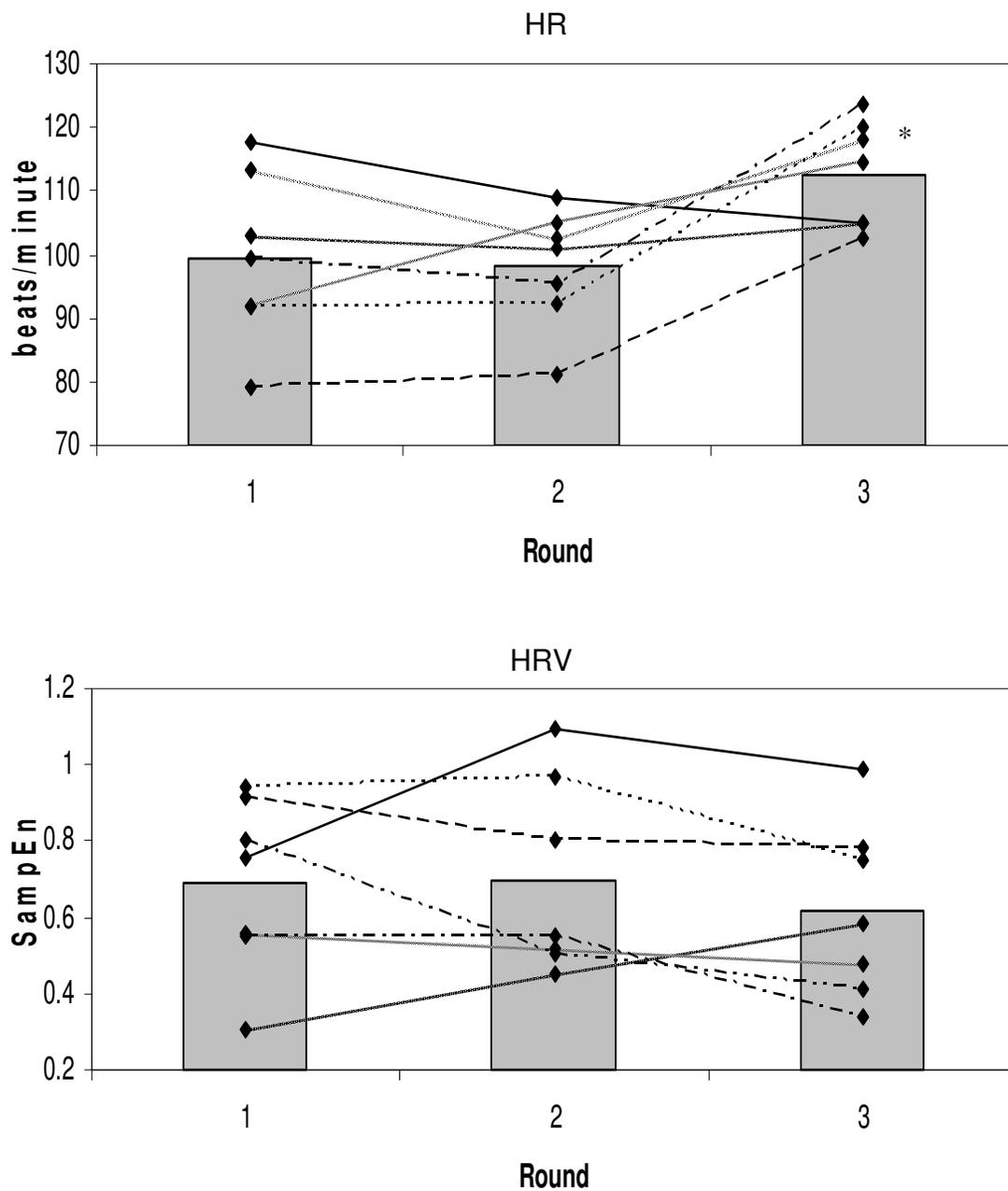


Figure 4. Mean HR and HRV in final round participants ( $n=7$ ) while putting in each round of Experiment 1. Bars represent group mean for each round, points connected by lines represent individual participants.  
 \* Significant difference in HR across rounds, see Table 2

**Hypotheses 4 and 5 – Lower postural sway variability and lower heart rate variability will be associated with better putting performance**

Pearson's  $r$  correlation coefficients between dependent variables for all participants in each round are displayed in Table 3 for Rounds 1 and 2 and Appendix D for Round 3. In Round 1, putting time showed a large correlation with ML sway while putting and a moderate correlation with AP sway while putting. HR during normal stance showed large correlations with HR and HRV while putting, and HRV during normal stance was significantly correlated with HRV while putting. HR while putting was negatively correlated with HRV while putting. ML sway variability during normal stance was moderately correlated with HR during normal stance. No correlations were found between HR and postural sway measures while putting, and no measures emerged as significant predictors of putting performance.

In Round 2, putting error was significantly correlated with both ML and AP sway variability while putting (see Figure 5 and Figure 6). Similar to Round 1, HR while putting was negatively correlated with HRV while putting, and HR during normal stance was significantly correlated with HR and HRV while putting. A moderate negative correlation was shown between ML sway variability during normal stance and HRV during normal stance. No significant correlations were found between measures of HR and postural sway variability while putting. Round 3 produced two significant correlations. Putting time was significantly correlated with ML sway variability and moderately correlated with AP sway variability while putting (see Appendix D).

Table 3

*a) Correlations Between Round 1 Dependent Variables in Experiment 1 (n=19)*

Variable	1	2	3	4	5	6	7	8	9	10
1. PuttError	-	.23	-.21	-.01	-.02	-.32	-.27	.02	-.17	.19
2. MLPre		-	.39	.52*	-.30	-.22	-.08	.15	.33	-.33
3. APPre			-	-.30	-.05	-.09	-.10	.15	-.21	.06
4. HRPre				-	-.24	.19	.25	.18	.93*	-.78*
5. HRVPre					-	-.30	-.36	.17	-.17	.48*
6. TimePutt						-	.83*	.57*	.27	-.33
7. MLPutt							-	.62*	.32	-.35
8. APPutt								-	.21	-.08
9. HRPutt									-	-.81*
10. HRVPutt										-

*b) Correlations Between Round 2 Dependent Variables in Experiment 1 (n=15)*

Variable	1	2	3	4	5	6	7	8	9	10
1. PuttError	-	-.13	-.38	-.02	.10	.15	.57*	.53*	-.27	.15
2. MLPre		-	.08	.32	-.54*	-.23	-.06	-.25	.39	.17
3. APPre			-	-.04	.10	-.53*	-.48	-.37	.07	-.31
4. HRPre				-	-.49	.31	.37	.12	.91*	-.63*
5. HRVPre					-	.21	-.03	.29	-.39	.15
6. TimePutt						-	.28	.10	.32	-.24
7. MLPutt							-	.65*	.18	.03
8. APPutt								-	-.08	.09
9. HRPutt									-	-.60*
10. HRVPutt										-

\* p &lt; .05

Figure 5. Putting Performance vs. ML Sway in Rounds 1 and 2 in Experiment 1

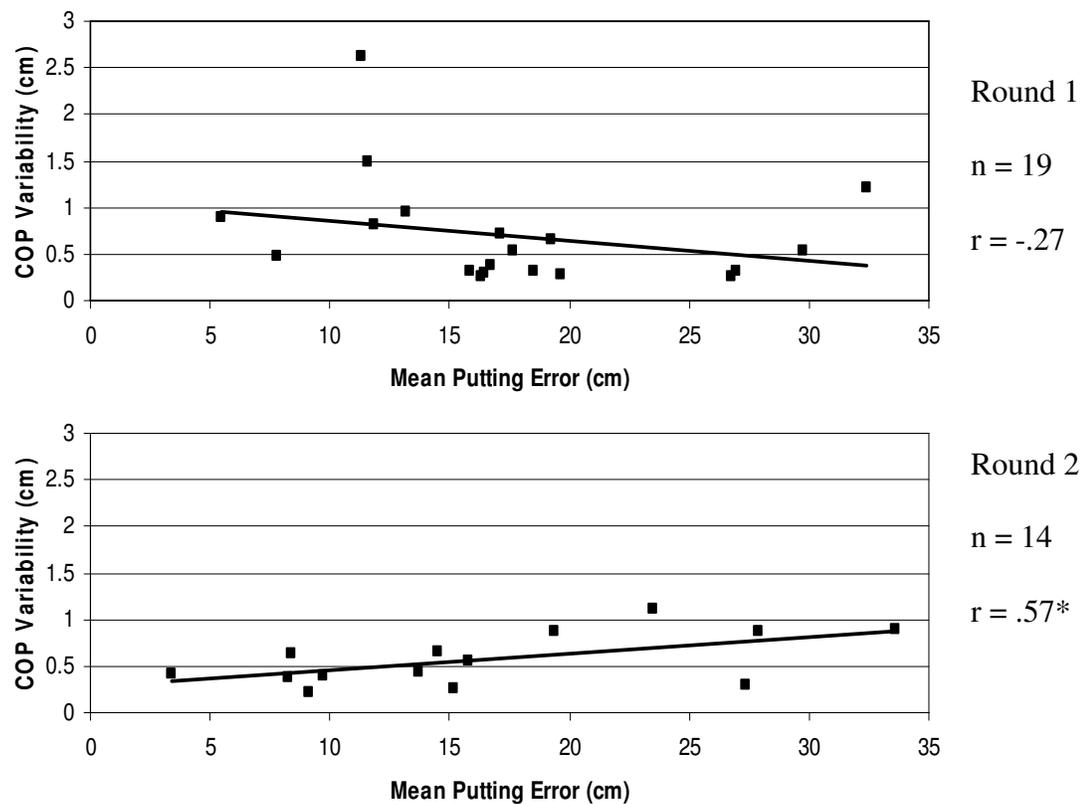


Figure 5. Relationship between putting performance and ML sway in Rounds 1 and 2 in Experiment 1.

\*  $p < .05$ 

Note. Postural sway data available for 19 participants in Round 1, 14 participants in Round 2.

Figure 6. Putting Performance vs. AP Sway in Rounds 1 and 2 in Experiment 1

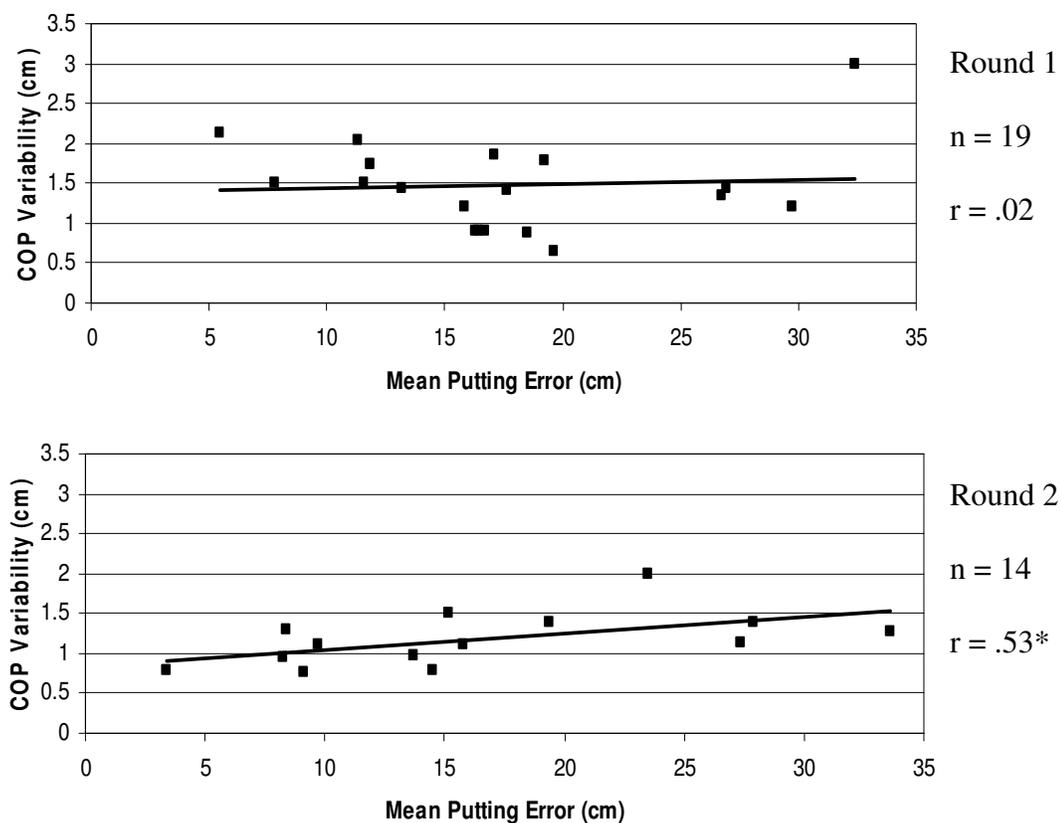


Figure 6. Relationship between putting performance and AP sway in Rounds 1 and 2 in Experiment 1.

\*  $p < .05$ 

Note. Postural sway data available for 19 participants in Round 1, 14 participants in Round 2.

## Experiment 1 Summary

The competitive environment produced several significant changes in experienced golfers. With regard to postural sway, participants exhibited significantly lower AP sway while putting in Round 2 compared to Round 1, and this was supported by a large effect size. In Round 1, postural sway measures were not related to performance. However, lower postural sway in both the ML and AP axes was associated with better putting performance in Round 2. This is likely a result of participants being engaged in a more competitive golf putting task. These findings support the hypotheses that postural sway would decrease in a more competitive situation and that lower postural sway variability would be associated with better putting performance.

This study also measured the effects of a competitive situation on HR and HRV, and examined whether HRV would relate to performance. While no changes in HR were seen within subjects in the first two rounds, final round participants showed higher HR in the last round, supporting the hypothesis that HR would increase in a more competitive situation. While it was hypothesized that HRV would decrease within subjects in a more competitive situation, no significant changes were found across rounds, though the decreased HRV in the final round was in the expected direction. Also, HRV was not significantly correlated with putting performance in any round, which did not support the hypothesis that lower HRV would be associated with better performance.

While support was found for three of the five research hypotheses, limitations of Experiment 1 may have prevented the discovery of more significant results. For example, the putting task in Round 3 was longer and more difficult than the earlier rounds, which may have influenced measures of postural sway and HRV. Other limitations of

Experiment 1 were discussed in Chapter III. As previously stated, Experiment 2 was designed to address those limitations. Also, since previous research has demonstrated various differences between performers of differing skill levels, Experiment 2 involved participants that were not experienced golfers to determine if the results of Experiment 1 could be replicated in a sample of less-skilled performers.

### **Experiment 2 Results**

Abbreviations for dependent variables, within-subject comparisons of ML sway, AP sway, HR, HRV, and SGR measures recorded prior to performance in each round, and variables measured during performance and associated effect sizes for all Round 1 and Round 2 participants are provided in Appendix E. Measures of postural sway, HR, and HRV recorded during performance in final round participants across all three rounds are displayed in Table 4, and measures of putting performance and putting time across all three rounds are displayed in Appendix E.

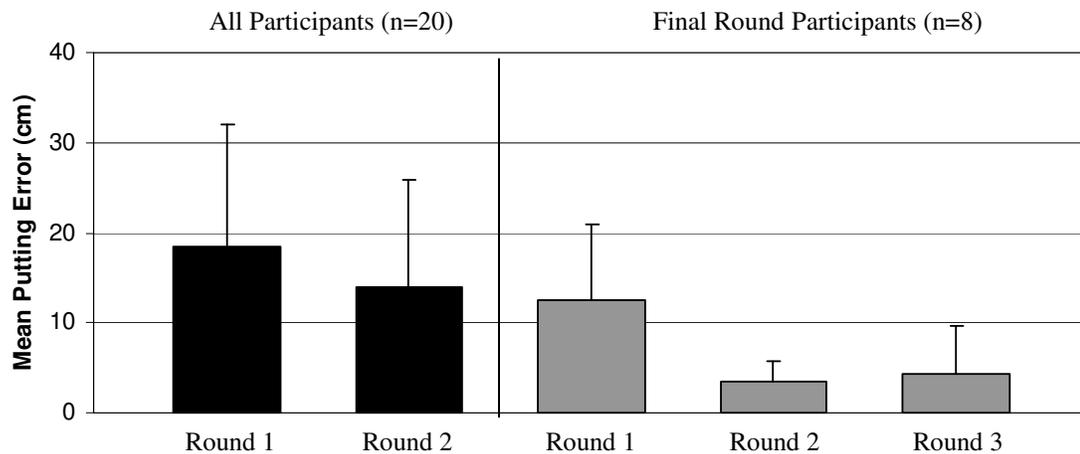
For all participants in the first two rounds, the 2 x 2 (Round x Putting Task) RM ANOVA showed a significant effect for Putting Task, Wilks'  $\lambda = .29$ ,  $F(6, 14) = 5.82$ ,  $p = .00$ , but not for Round, Wilks'  $\lambda = .59$ ,  $F(6, 14) = 1.65$ ,  $p = .21$ , or the Round x Putting Task interaction, Wilks'  $\lambda = .73$ ,  $F(6, 14) = 0.86$ ,  $p = .55$ . For participants that completed all three rounds, the 3 x 2 (Round x Putting Task) RM ANOVA did not show a significant effect for Round, Wilks'  $\lambda = .19$ ,  $F(12, 18) = 1.96$ ,  $p = .10$ , Putting Task, Wilks'  $\lambda = .18$ ,  $F(6, 2) = 1.48$ ,  $p = .46$ , or the Round x Putting Task interaction, Wilks'  $\lambda = .23$ ,  $F(12, 16) = 1.64$ ,  $p = .17$ . However, the 3 x 2 RM ANOVA did produce statistically significant univariate tests for both HRV while putting and putting performance, and follow-up pairwise comparisons were performed as a result (see Table

4b and Appendix E). Pearson correlation coefficients between dependent variables for all participants in each round are provided in Appendix E. Results are described further in the following sections.

With respect to putting performance for all participants in Rounds 1 and 2, univariate tests from the 2 x 2 (Round x Putting Task) RM ANOVA showed significant effects of Round,  $F(1, 19) = 7.73, p = 0.01$ , and Putting Task,  $F(1, 19) = 19.56, p = .00$ , on putting performance, but the Round x Putting Task interaction was not significant,  $F(1, 19) = 0.23, p = .64$ . Generally, participants performed better on the short putt task compared to the long putt task within both rounds, and they also had better performance in Round 2 compared to Round 1 (see Figure 7 and Appendix E). For final round participants, the 3 x 2 (Round x Putting Task) RM ANOVA showed a significant effect of Round on putting performance,  $F(2, 14) = 7.78, p = .01$ , but Putting Task,  $F(1, 7) = 2.16, p = .19$ , and the Round x Putting Task interaction,  $F(2, 14) = 0.86, p = .44$ , were not significant. Overall, final round participants had more putting error (lower performance) in Round 1 compared to Rounds 2 and 3 (see Figure 7 and Appendix E).

Figure 7

## a) Long Putt Performance in Experiment 2



## b) Short Putt Performance in Experiment 2

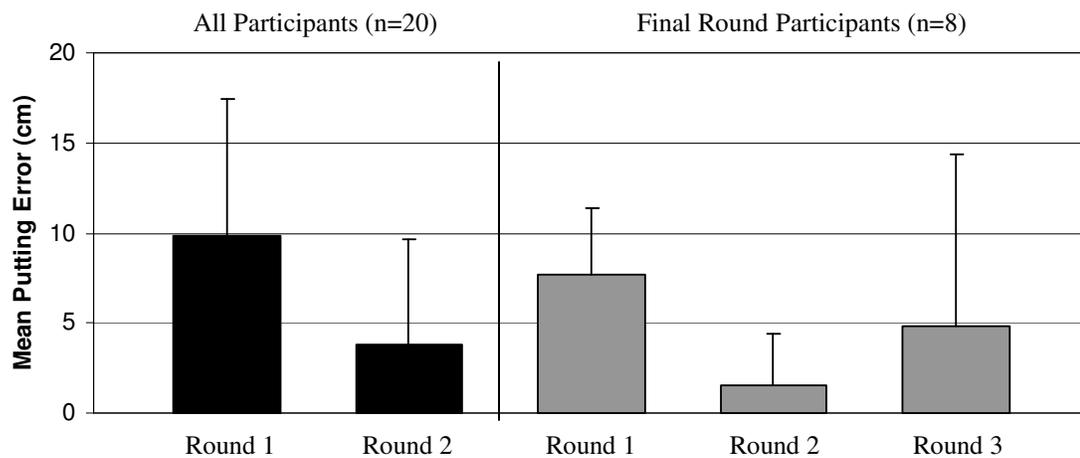


Figure 7. Putting performance in Rounds 1 and 2 and Across Rounds 1, 2, and 3 in Experiment 2. Bars represent group means, error bars represent standard deviations.

Note. Results of statistical tests comparing these variables are provided in the text and Appendix E.

Regarding putting time, the 2 x 2 (Round x Putting Task) RM ANOVA did not show a significant effect of Round on putting time within all participants in the first two rounds,  $F(1, 19) = 0.23$ ,  $p = .64$ , and the Round x Putting Task interaction was also not significant,  $F(1, 19) = 0.52$ ,  $p = .48$ . However, there was a significant effect of Task on putting time,  $F(1, 19) = 16.91$ ,  $p = .00$  as participants tended to have longer putting times during the long putt condition in each of the first two rounds (see Appendix E). Similar effects were shown in final round participants, as the 3 x 2 (Round x Putting Task) RM ANOVA found no significant effect of Round,  $F(2, 14) = 1.04$ ,  $p = .38$ , or the Round x Putting Task interaction,  $F(2, 14) = 0.04$ ,  $p = .96$ , on putting time, but Task did have a significant effect,  $F(1, 7) = 6.98$ ,  $p = .03$ . Participants that completed all three rounds tended to have longer putting times when attempting longer putts compared to short putts (see Appendix E). For SGR measures, Wilcoxon signed rank tests showed no significant differences in *Worry* or *Activation* within all participants when comparing Round 1 and Round 2, and RM ANOVAs showed no changes in *Worry* or *Activation* in participants that completed all three rounds (see Appendix E).

### **Hypothesis 1 – Postural sway variability will decrease in a more competitive condition**

Paired t-tests showed significant increases in ML and AP sway variability during normal stance from Round 1 to Round 2 (see Appendix E). The change in ML sway was associated with a trivial effect size while the change in AP sway was associated with a moderate effect size. When comparing within all participants in the first two rounds, univariate tests from the 2 x 2 (Round x Putting Task) RM ANOVA did not show a significant effect of Round on ML sway,  $F(1, 19) = 0.11$ ,  $p = .74$ , or AP sway,  $F(1, 19) =$

1.29,  $p = .27$ , while putting. Likewise, there was not a significant effect of Putting Task on ML sway,  $F(1, 19) = 2.19$ ,  $p = .16$ , or AP sway,  $F(1, 19) = 0.17$ ,  $p = .68$ , and the Round x Putting Task interaction was not significant for ML sway,  $F(1, 19) = 0.15$ ,  $p = .71$ , or AP sway,  $F(1, 19) = 0.75$ ,  $p = .40$ , while putting. There were no within-subject differences in ML sway or AP sway while putting when comparing the long and short putt conditions or Round 1 and Round 2.

For participants that competed in all three rounds, RM ANOVAs showed no significant changes in ML sway during normal stance,  $F(2, 14) = 1.88$ ,  $p = .19$ , or AP sway during normal stance,  $F(2, 14) = 1.81$ ,  $p = .20$ . Also, univariate tests from the  $3 \times 2$  (Round x Putting Task) RM ANOVA showed ML sway was not significantly affected by Round,  $F(2, 14) = 1.68$ ,  $p = .22$ , Putting Task,  $F(1, 7) = 0.99$ ,  $p = .35$ , or the Round x Putting Task interaction,  $F(2, 14) = 1.77$ ,  $p = .21$ . AP sway in final round participants was also not affected by Round,  $F(2, 14) = 0.60$ ,  $p = .56$ , Putting Task,  $F(1, 7) = 1.13$ ,  $p = .32$ , or the Round x Putting Task interaction,  $F(2, 14) = 0.94$ ,  $p = .41$ . Once again, ML sway and AP sway while putting were not affected by the putting task or the round.

### **Hypotheses 2 and 3 - HR will increase and HRV will decrease in a more competitive condition**

Paired t-tests showed no significant differences in HR,  $t(19) = 0.93$ ,  $p = .36$ , or HRV,  $t(19) = -0.16$ ,  $p = .88$ , during normal stance within participants between Rounds 1 and 2 (see Appendix E). Also, HR while putting did not change within all participants in the first two rounds, as univariate tests from the  $2 \times 2$  (Round x Putting Task) RM ANOVA did not show a significant effect of Round,  $F(1, 19) = 0.00$ ,  $p = .96$ , Putting Task,  $F(1, 19) = 2.95$ ,  $p = .10$ , or the Round x Putting Task interaction,  $F(1, 19) = 1.44$ ,  $p$

= .25, on HR while putting. Likewise, HRV was not significantly affected by Round,  $F(1, 19) = 0.05$ ,  $p = .82$ , Putting Task,  $F(1, 19) = 0.01$ ,  $p = .94$ , or the Round x Putting Task interaction,  $F(1, 19) = 1.97$ ,  $p = .18$ , for all participants in the first two rounds.

For participants that completed all three rounds, RM ANOVAs showed no significant differences in HR,  $F(2, 14) = 0.89$ ,  $p = .43$ , or HRV,  $F(2, 14) = 0.98$ ,  $p = .40$ , during normal stance before each round (see Appendix E). Also, the 3 x 2 (Round x Putting Task) RM ANOVA showed HR while putting was not significantly affected by Round,  $F(2, 14) = 2.70$ ,  $p = .10$ , Putting Task,  $F(1, 7) = 5.30$ ,  $p = .06$ , or the Round x Putting Task interaction,  $F(2, 14) = 1.03$ ,  $p = .38$ , though participants tended to have higher HR while putting in Round 3 (see Table 4a and Figure 8). Additionally, HRV while putting was not significantly affected by Putting Task,  $F(1, 7) = 0.35$ ,  $p = .57$ , or the Round x Putting Task interaction,  $F(2, 14) = 1.82$ ,  $p = .20$ , but Round did have a significant effect on HRV while putting in final round participants,  $F(2, 14) = 3.78$ ,  $p = .05$ , as HRV was lower within participants in Round 3 during both putting conditions compared to Rounds 1 and 2 (see Table 4 and Figure 8).

Table 4

*a) Performance Variables for Finalists (n=8) in Rounds 1, 2, and 3 in Experiment 2*

Measure	Round 1 Mean (SD)	Round 2 Mean (SD)	Round 3 Mean (SD)
MLLong	0.35 (0.24)	0.31 (0.16)	0.46 (0.32)
MLShort	0.31 (0.15)	0.34 (0.22)	0.36 (0.26)
APLong	0.89 (0.31)	0.99 (0.41)	1.07 (0.37)
APShort	0.96 (0.57)	0.84 (0.31)	0.92 (0.37)
HRLong	88.6 (14.0)	91.5 (9.8)	101.3 (14.3)
HRShort	88.5 (14.9)	89.4 (7.6)	98.1 (14.0)
HRVLong	1.20 (0.39)	1.05 (0.21)	0.76 (0.31)
HRVShort	1.11 (0.37)	1.11 (0.28)	0.85 (0.25)

Note. Results of statistical tests comparing these variables are provided in the text

*b) Pairwise Comparisons of HRV During Long Putt and Short Putt Performance Across Rounds 1, 2, and 3 in Experiment 2*

Measure	Rounds	Mean (SD)	p	Effect Size <i>d</i>	
HRVLong	1, 2	1.20 (0.39), 1.05 (0.21)	1.000	0.48	
	n = 8	1, 3	1.20 (0.39), 0.76 (0.31)	.053	1.25
		2, 3	1.05 (0.21), 0.76 (0.31)	.010*	1.10
HRVShort	1, 2	1.11 (0.37), 1.11 (0.28)	1.000	0.00	
	n = 8	1, 3	1.11 (0.37), 0.85 (0.25)	.334	0.82
		2, 3	1.11 (0.28), 0.85 (0.25)	.327	0.98

\* $p < .017$  (Bonferroni adjustment,  $.05/3$ )

Figure 8. HR and HRV in Finalists Across Rounds in Experiment 2

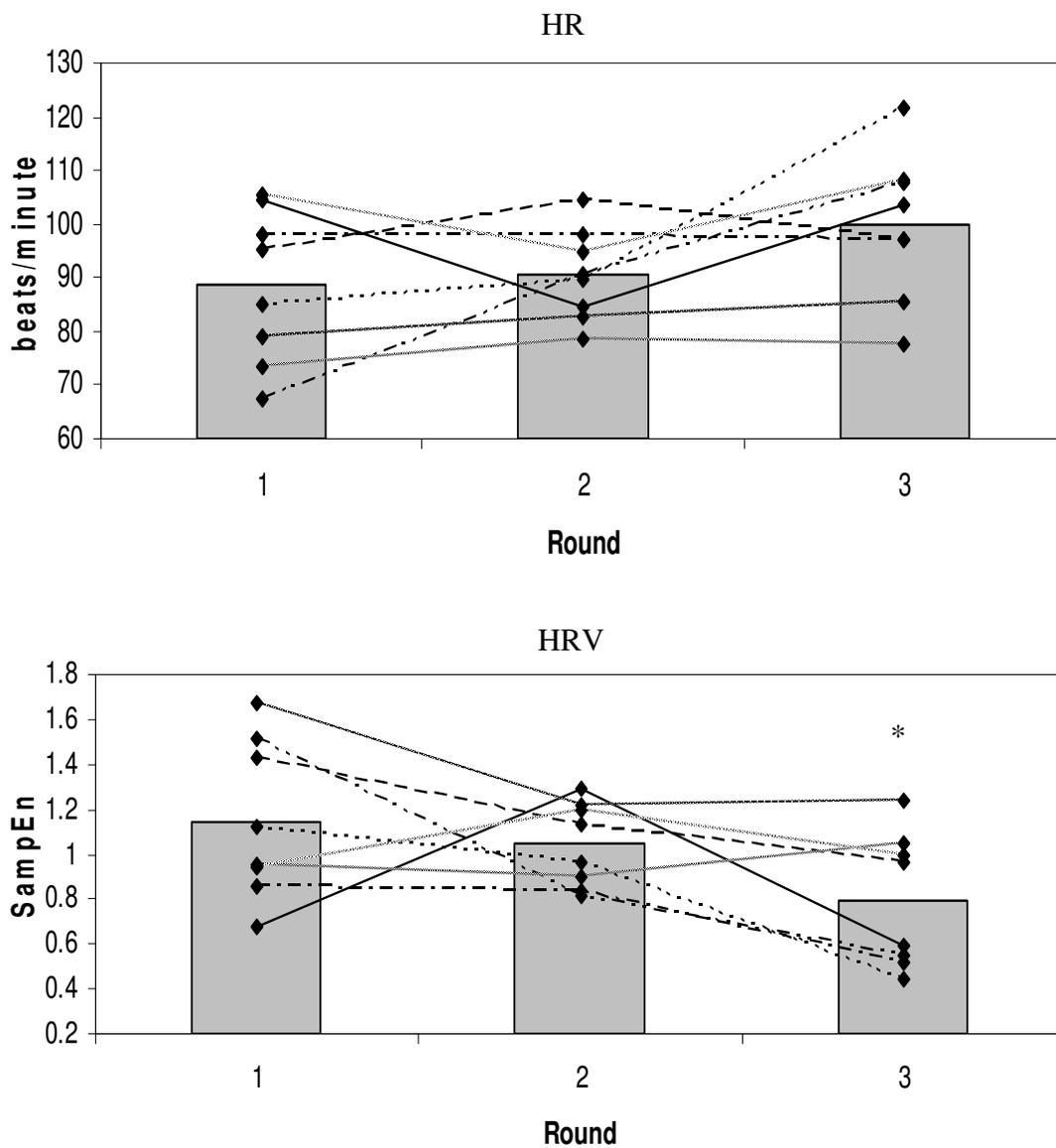


Figure 8. Mean HR and HRV in final round participants (n=8) while putting in each round in Experiment 2. Bars represent mean for each round, points connected by lines represent individual participants.

\* Significant difference in HRV across rounds, see Table 4b

Note. Since neither HR nor HRV differed between long and short putt conditions within each round, the mean values for each round are shown in this figure.

**Hypotheses 4 and 5 – Lower postural sway variability and lower heart rate variability will be associated with better putting performance**

Pearson's  $r$  correlation coefficients between dependent variables for all participants in each round are displayed in Appendix E. In Round 1, HR was negatively correlated with HRV during both normal stance and putting conditions. There was also a moderate negative correlation between HRV and putting time during the long putt condition. Putting time in the short putt condition was negatively correlated with both ML and AP sway variability in the short putt condition. Lastly, *Worry* was negatively correlated with AP sway in the long putt condition. No measures were significantly correlated with putting performance in Round 1.

In Round 2, HR was again negatively correlated with HRV in both the normal stance and putting conditions. AP sway during normal stance was moderately correlated with HR during normal stance and in both the long and short putt conditions. *Activation* was significantly correlated with HR during the long putt condition. Several predictors of performance were found. Similar to Experiment 1, ML and AP sway variability in the long putt condition were both positively correlated with putting error in the long putt condition (see Figure 9 and Figure 10). Also, HRV measured during the short putt condition was positively correlated with putting error in the short putt condition (see Figure 11).

A number of significant correlations were found in Round 3. Reported feelings of *Worry* and *Activation* showed moderate correlations with HR during both long and short putting conditions. HRV while putting was positively correlated with putting time in both the long and short putt conditions. Concerning putting performance, there was a large

negative correlation between *Activation* and putting error in the long putt condition.

Also, HRV while putting was moderately correlated with putting error in the short putt condition (see Figure 11).

Figure 9. Long Putt Performance vs. ML Sway Across Rounds in Experiment 2

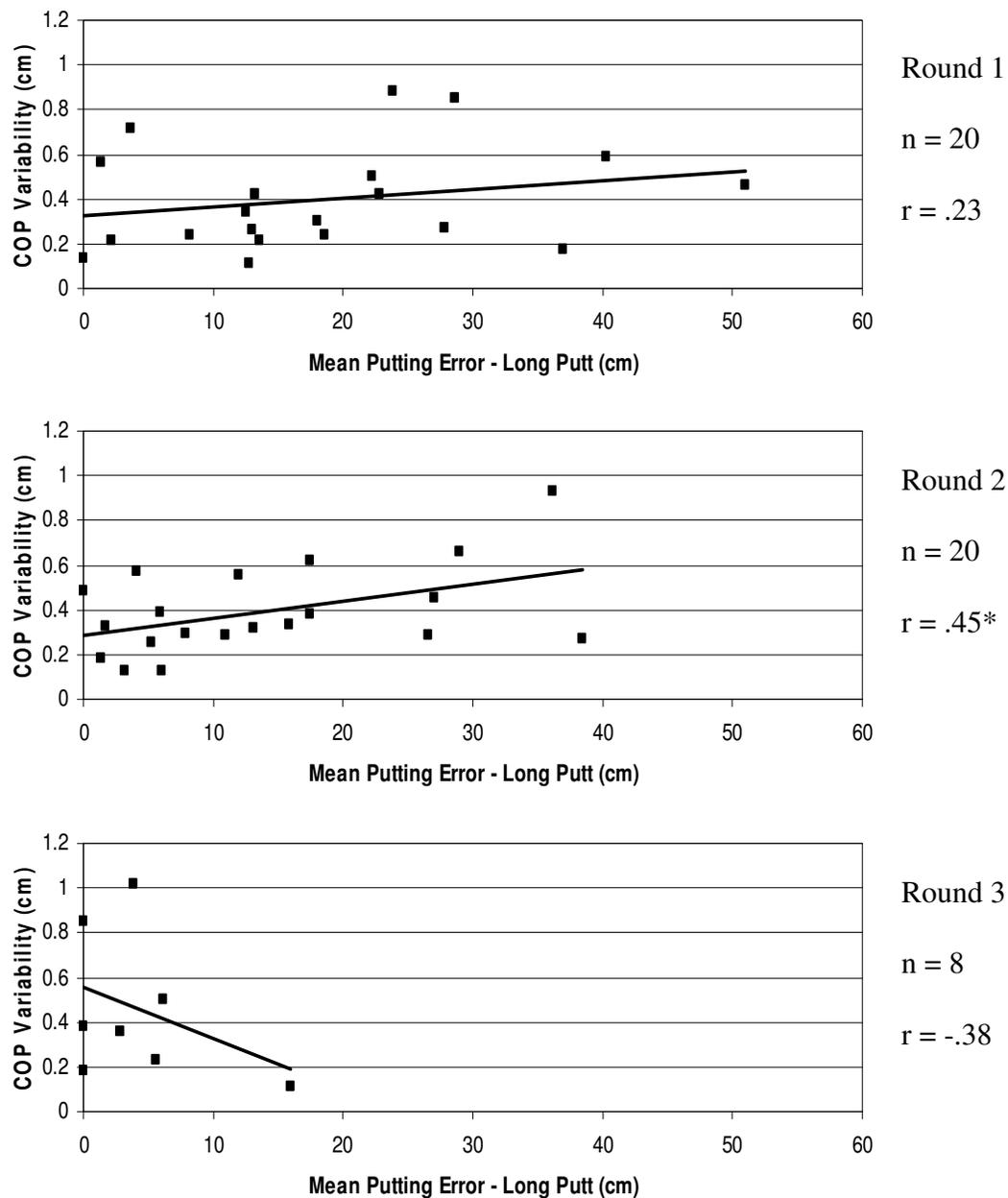


Figure 9. Relationship between long putt (5.5 feet) performance and ML sway across rounds in Experiment 2.

\* p < .05

Figure 10. Long Putt Performance vs. AP Sway Across Rounds in Experiment 2

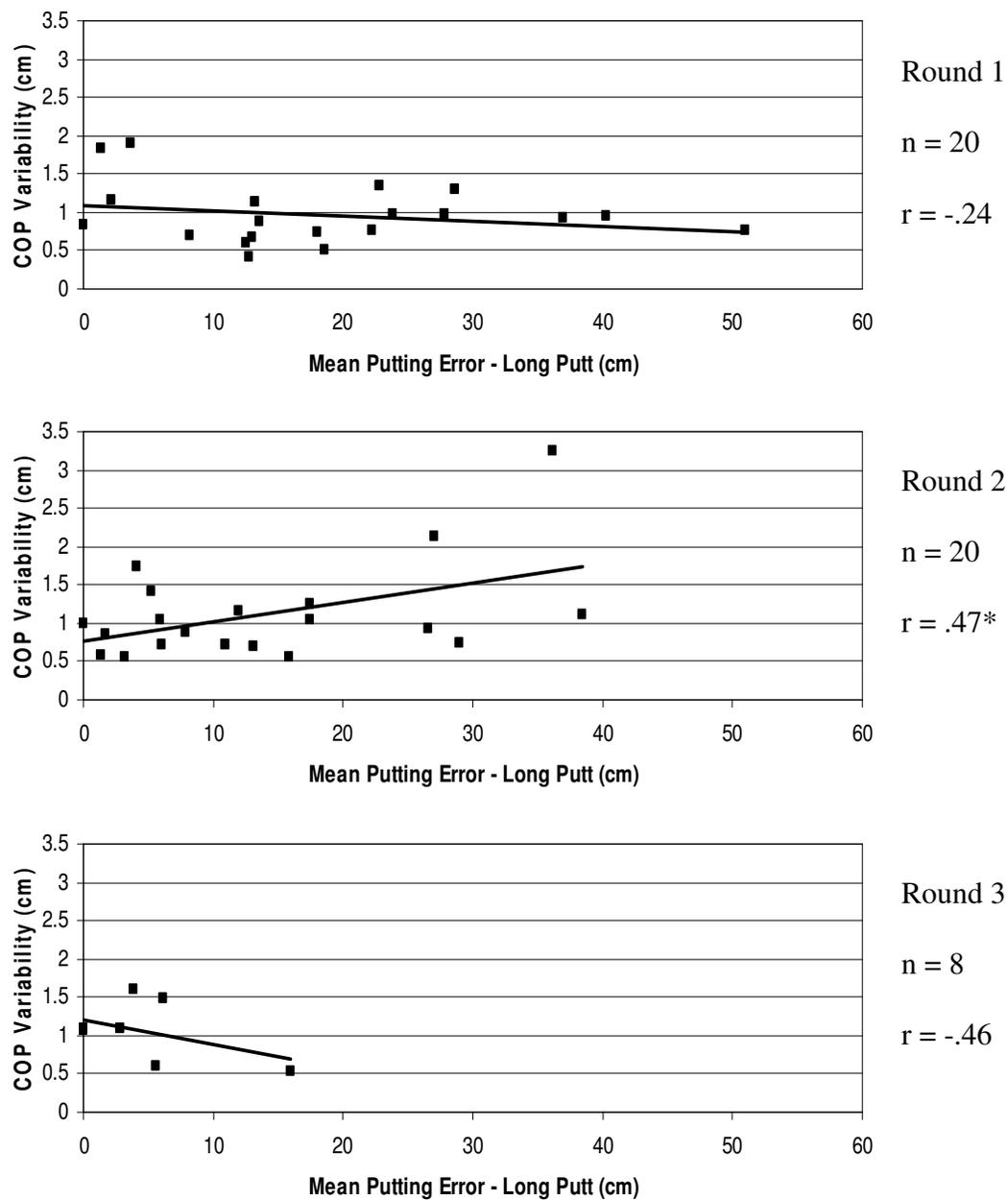


Figure 10. Relationship between long putt (5.5 feet) performance and AP sway across rounds in Experiment 2.

\* p &lt; .05

Figure 11. Short Putt Performance vs. HRV Across Rounds in Experiment 2

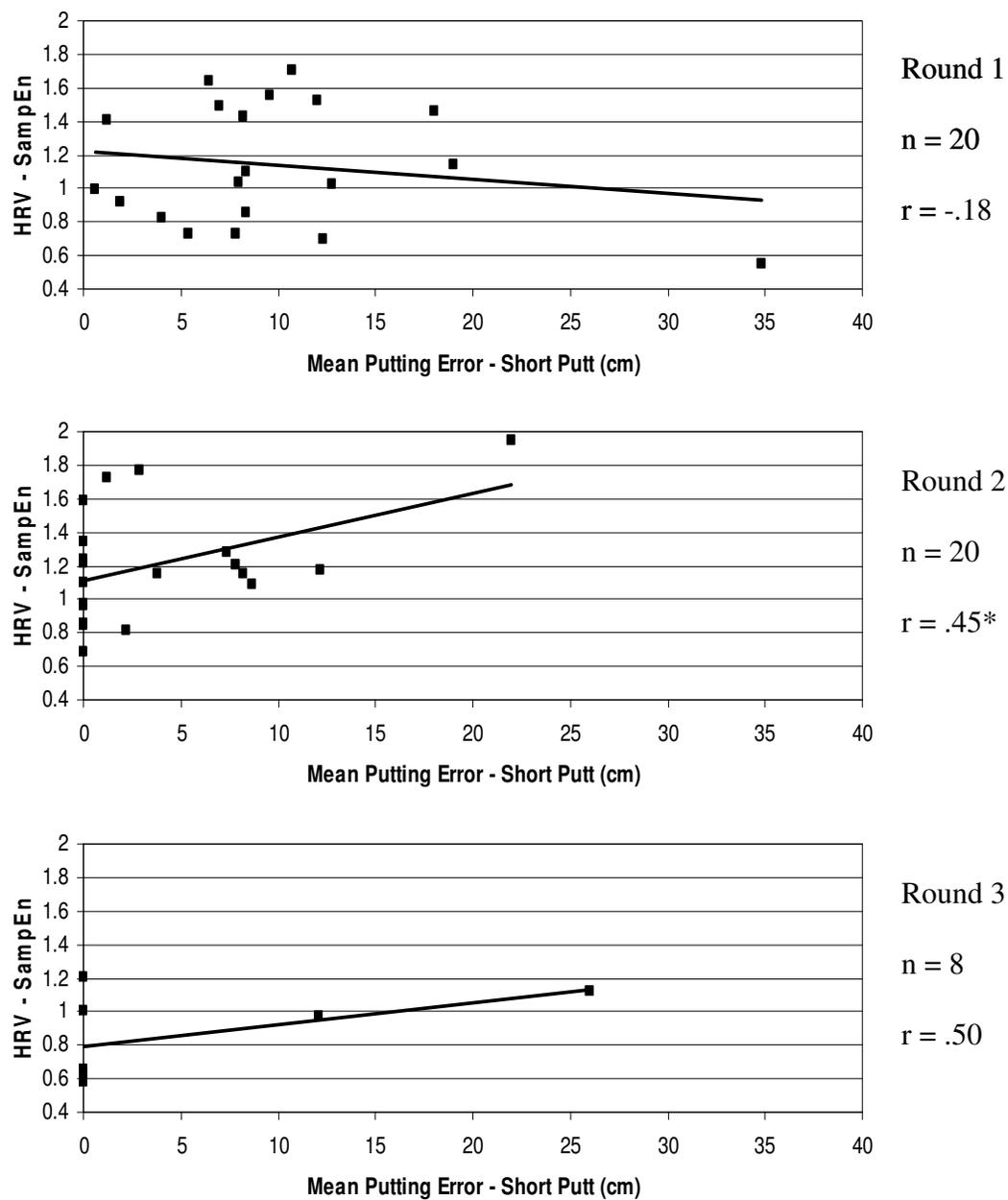


Figure 11. Relationship between short putt (3.5 feet) performance and HRV across rounds in Experiment 2.

\* p < .05

## **Experiment 2 Summary**

Experiment 2 followed a similar protocol to Experiment 1 and tested the same five hypotheses. The belief that postural sway variability would decrease in a more competitive situation was not supported in Experiment 2, as ML and AP sway while putting did not differ significantly within participants across rounds. It was also hypothesized that lower postural sway would be associated with better putting performance. Similar to Experiment 1, this hypothesis was supported, as lower ML and AP sway was associated with better putting performance in the long putt condition in Round 2. Regardless of whether participants were experienced golfers or not, within each experiment, lower postural sway predicted better putting performance in the more competitive round.

Similar to Experiment 1, HR and HRV while putting did not differ significantly within subjects between Rounds 1 and 2. In final round participants, though, HRV was significantly lower in the final round, supporting the hypothesis that HRV would decrease in a more competitive environment. Though it was postulated that HR would increase in a more competitive situation, increases in HR in the final round of Experiment 2 did not reach statistical significance, though trends were in the predicted direction. The final hypothesis stated that lower HRV would correlate with better putting performance. This received partial support, as lower HRV was associated with better putting performance in the short putt condition of Round 2 and Round 3. Results across Experiments 1 and 2 provided support for all five research hypotheses. Generally speaking, lower postural sway was associated with better putting performance in the second round, while the final round tended to result in increased HR and decreased HRV.

## Discussion

The present research was guided by implications of EC theory, which emphasizes the synergy between motor action and the mental state of the performer in the environment, and differs from the traditional cognitive science view of a dichotomous relationship between the mind and the body. When discussing EC theory, Araujo and Davids (2004) noted the importance of considering categories of constraints related to motor skill performance. According to Newell (1986), individual, environmental, and task constraints all determine the movement capabilities of individuals, and the interactions between these constraints also determine how motor skills can be performed.

Golf putting performance is affected by numerous factors related to the individual, the environment, and the task, and all three of Newell's (1986) constraints were considered in the present research. Individual constraints included biological measures such as postural sway and cardiovascular responses, as well as the inclusion of different levels of experience. Environmental constraints were a primary concern in the present study, as the competitive atmosphere was manipulated through the use of a monetary reward and putting in front of an audience. Task constraints also played a role, as participants were provided with specific instructions on how to perform the putting task in each experiment. Experiment 2 also included two putting tasks of unequal difficulty. The consideration of all of these constraints helped provide a more comprehensive understanding of golf putting under pressure.

The study was designed to assess the following research question: Do postural sway, HR, and HRV change as a function of competitive setting in golf putting, and how do these changes affect performance? Five hypotheses accompanied this question. It was

believed that a more competitive setting would result in decreased postural sway variability, higher HR, and lower HRV. It was also hypothesized that lower postural sway variability and lower HRV would predict better golf putting performance. Support was found for all of these hypotheses to varying degrees, and each of these is discussed further.

Postural sway has been shown to facilitate the performance of perceptual motor tasks (Stoffregen et al., 2006; Stoffregen et al., 2007). Within each experiment, lower postural sway was associated with better putting performance in the second round. In Experiment 1, lower postural sway in both the ML and AP axes was associated with better putting performance in Round 2, and participants showed a significant decrease in AP sway from Round 1 to Round 2. In Experiment 2, lower ML and AP sway were again associated with better putting performance in Round 2, though this effect was limited to the long putt condition. It is possible that performance of a relatively longer putting task may benefit from reduced postural sway more so than a shorter putting task, as postural sway variability did not differ within subjects when comparing long and short putts. These findings support the hypothesis that lower postural sway would predict better putting performance and are consistent with previous research that has shown postural sway's role in facilitating the performance of other tasks (Riley et al., 2003; Riley et al., 2005; Stoffregen et al., 2006; Stoffregen et al., 2007). While ML and AP sway during normal stance did not change from Round 1 to Round 2 in Experiment 1, participants in Experiment 2 showed a significant increase in these measures from Round 1 to Round 2. Since participants were provided with the same instructions regarding normal stance before each round, there does not appear to be clear explanation for this finding.

Measures of HR and HRV have been employed as indicators of arousal and attention in numerous research studies (Murray & Raedeke, 2008; Mullen et al., 2005; Wilson et al., 2007). Increased arousal is associated with higher HR and lower HRV, and reduced HRV may also indicate greater attention to a task. HR was negatively correlated with HRV while putting in Rounds 1 and 2 in both experiments. This is to be expected, as increased HR is generally associated with decreased HRV. In both experiments, HR and HRV did not change significantly within subjects between Rounds 1 and 2. In the final round of Experiment 1, participants showed a significant increase in HR and a nonsignificant decrease in HRV while putting. In Experiment 2, final round participants had a nonsignificant increase in HR along with a significant decrease in HRV while putting. These findings lend support to the hypotheses that HR would increase and HRV would decrease in a more competitive situation. In both experiments, Round 3 induced more physiological arousal in participants than Round 2, though both rounds were designed to be more competitive than Round 1. Since Round 3 included the opportunity to win a large monetary reward, it had a greater impact on arousal than Round 2. Larger samples sizes in a final round competition would likely show significant changes in both HR and HRV.

In Experiment 1, HR and HRV were not significantly correlated with postural sway variability or putting performance. However, these cardiovascular measures did correlate with other variables in Experiment 2. In Round 1, decreased HRV was associated with longer putting time in the long putt condition. In Round 3, however, the opposite effect was found, as decreased HRV was correlated with shorter putting time values in both the long and short putt conditions. Intuitively speaking, the Round 1 result

seems more likely, as both lower HRV and longer putting time would indicate that inexperienced golfers were paying more attention to the task. However, it could also be true that participants in Round 3 with lower HRV were more focused and therefore required less time to attempt the putt. Since putting time has not been established as a measure of attention or effort, it is beyond the scope of this paper to discuss this issue further.

Contrary to Experiment 1, HRV was a significant predictor of performance in Experiment 2. Lower HRV was associated with better performance in the short putt condition of both Round 2 and Round 3. These results must be interpreted cautiously, however, as Round 3 consisted of a relatively small sample size, and many participants in Round 2 successfully holed all of their short putts. These factors limit the strength of the relationship between HRV and short putt performance in Experiment 2. Differences in skill level may explain why HRV was associated with putting performance in beginners but not experienced golfers, but the putting tasks in the final round of each experiment were not similar and could not be directly compared. Since this effect was only found in Experiment 2, further research is needed to explain how HRV is related to putting performance in a high pressure situation.

Experiment 2 included the SGR as an additional measure of arousal. Specifically, this instrument asks participants to indicate both their degree of worry and activation prior to performance. In Experiment 2, feelings of worry and activation did not differ significantly within subjects across rounds. However, in Round 3, *Worry* and *Activation* were both positively correlated with HR in the long and short putt conditions, and higher *Activation* was associated with greater HR during the long putt condition in Round 2,

showing that the SGR may be appropriate for measuring arousal in competitive situations. Increased feelings of activation were also associated with better putting performance in the final round. While this finding is limited to a sample of eight participants, it suggests that a relatively low level of activation may not be beneficial for golf putting in a high pressure situation. Performers may often be encouraged to stay relaxed and calm when performing a skill such as golf putting, but a certain level of activation is needed for better performance.

In an unpublished doctoral dissertation involving four amateur golfers, Robb (2005) found the SGR could be used to help predict golf performance. Increased *Worry* was associated with impaired performance, while increased *Activation* tended to have a positive influence on performance. Since the SGR was designed to assess feelings of worry and activation in athletes, it may be more applicable to experienced golfers rather than beginners. Also, a higher degree of competitive pressure may be needed to induce significant changes in SGR measures.

It is interesting to note that reduced postural sway measures, when significant, were beneficial for relatively long putts in Round 2 for both experiments, whereas lower HRV was more specifically associated with performance in the short putt condition in the later rounds of Experiment 2. HRV and postural sway variability are both complex processes that are influenced by a number of factors. It may be the case that cardiovascular measures are stronger predictors of performance when attempting short putts in a high-pressure situation, while postural sway variability plays a lesser (though necessary) role. Changes in postural sway were more strongly associated with performance in Round 2, while HR and HRV did not significantly change until Round 3

in both experiments. Cooke et al. (2010) argued the postural and physical demands of the golf putting task, though minimal, could override the effects of mental activity on cardiovascular measures such as HRV. In the case of the present study, changes in postural sway variability facilitated golf putting performance in a relatively competitive situation, but only to a certain extent. In the final round, cardiovascular measures (i.e., HRV) had a stronger association with performance. The final round was designed to have the highest level of pressure, and in this instance cardiovascular measures were not overridden by the postural and physical demands of the putting task. Though these relationships require further exploration, it is important to consider the competitive environment when studying the body's role in golf putting performance.

A secondary aim of this research was to compare participants of varying skill level. However, the performance context differed between Experiment 1 and Experiment 2, and different populations were sampled for each experiment. For instance, all participants in Experiment 1 were men, while both men and women participated in Experiment 2. Also, Experiment 1 participants were on average about 25 years older than Experiment 2 participants. Taking these differences into account, statistical comparisons between the two experiments would not be prudent. Since the putting task in the first two rounds of Experiment 1 was similar to the long putt task of Experiment 2, however, general comparisons were made.

Generally speaking, golfers from Experiment 1 exhibited more ML and AP sway while putting in both rounds compared to inexperienced golfers from Experiment 2. Since lower postural sway variability was associated with better golf putting performance within each experiment, it is interesting that skilled golfers would sway more than

inexperienced golfers while putting. The higher amount of postural sway in golfers could be attributed to differences in the putting task. For example, golfers putted on a raised platform in an outdoor environment, while beginners stood on a balance board that was level with a putting surface in an indoor facility. It is important to evaluate postural sway variability in the context of task performance.

Putting time was an additional variable that was recorded along with postural sway variability. While putting time was not a significant predictor of performance in either experiment, several differences were present when comparing the two experiments. Overall, experienced golfers took more time to putt than inexperienced golfers, as might be expected. Also, golfers took less time to putt in Round 2 compared to Round 1, while beginners did not change in that respect. Research has shown that experienced golfers can benefit from increased speed (less set-up time) when performing golf putts, while the opposite is true for inexperienced golfers (Beilock & Gonso, 2008). A decrease in putting time from Round 1 to Round 2 may have aided some participants in Experiment 1, but it must be mentioned that putting time did not predict putting performance. The fact that experienced golfers generally had longer putting times than beginners may again point to a difference in the difficulty of the putting task between the two experiments.

In Experiment 2, beginners had longer putting time values on long putts compared to short putts in Round 2 and Round 3. In this case, putting time may be an indicator of putt difficulty for inexperienced golfers. A wealth of research has demonstrated that longer visual fixations on a target can aid performance of perceptual motor tasks. This fixation period is generally referred to as quiet eye (Harle & Vickers, 2001; Williams, Singer, & Frehlich, 2002). Longer quiet eye durations have been associated with superior

performance in activities such as rifle shooting (Janelle et al., 2000), basketball free-throw shooting (Harle & Vickers, 2001), billiards (Williams et al., 2002), kicking a soccer ball (Nagano, Kato, & Fukuda, 2006), and goaltending in hockey (Panchuk & Vickers, 2006). Naito et al. (2003) found golfers use vision in different ways while putting depending on their level of experience, though elite golfers did not fixate on one specific target while putting in their study. Golf putting is a perceptual motor task, and significant differences in putting time may reflect different visual strategies used by golfers of varying levels of experience. However, vision was not tracked in this study, and further research is needed to explore the relationship between putting time and visual fixation strategies used by golfers.

Another interesting finding from the present research showed experienced golfers with longer putting times exhibited more ML and AP sway variability in Round 1 while putting, while inexperienced golfers with longer putting times had lower measures of ML and AP sway variability while putting in Round 1. This may demonstrate fundamental differences in postural sway variability during the putting motion in golfers of varying experience. The importance of this finding is difficult to gauge, however, as it was only found in one round, and postural sway was not a significant predictor of performance in Round 1 of either of experiment.

Regarding cardiovascular measures, golfers tended to have higher HR and lower HRV than inexperienced golfers while putting in both Rounds 1 and 2. Since baseline measures of HR were similar in experienced and inexperienced golfers in both rounds, the higher HR in golfers while putting may indicate they had a higher degree of arousal than beginners. Lower HRV in experienced golfers could also indicate they were more

engaged in the putting task. However, Neumann and Thomas (2009) found elite and experienced golfers had higher HRV while putting compared to novices, and suggested more skilled players did not have to allocate as much attention to the task in their study. When comparing the two experiments in the present study, the likely difference in difficulty between the two tasks may help explain why experienced golfers had lower HRV than inexperienced participants, though the application of this finding is again limited.

Experienced and inexperienced participants were similar in putting performance in both Round 1 and Round 2. While experienced golfers might be expected to perform better, the putting task in Experiment 1 may have been more difficult than the long putt task in Experiment 2. To achieve a more ecologically valid design, Experiment 1 was conducted on an outdoor putting green that was not perfectly flat and was exposed to weather conditions. Experiment 2, however, was conducted in a controlled, indoor environment and utilized a platform with a flat, consistent putting surface, limiting the comparisons that can be made between performance in experienced and inexperienced golfers in this study.

Several other limitations were present in the study. Participants in Experiment 1 performed the same putt 15 times in each of the first two rounds, but putted from a longer distance in the final round. This limited the ability to compare differences across all three rounds in the first experiment. In both experiments, the sample size for the final round was relatively small, which may have hindered the ability to find statistical significance even though several effects were found. Including more participants in the final round could provide more substantial results. Also, it is possible that the presence of moderate

to large correlations between several of the dependent variables measured (ML sway was correlated with AP sway and HR was correlated with HRV, for example) may increase the likelihood of a Type I error when performing multiple statistical tests. However, since ML sway and AP sway are both measures of postural sway variability and HR and HRV are both related to cardiovascular activity, this does not appear to be a major concern. Also, the use of putting time as a variable did result in some interesting findings, but it is not as specific or advanced as other variables that have been used to measure phases of the putting stroke in other research (Delay et al., 1997; Tanaka & Sekiya, 2010; Toner & Moran, 2011).

Finally, though all participants in Experiment 2 were inexperienced golfers, it is possible that some possessed superior motor abilities compared to others, producing a wide skill level range within the inexperienced group. Some participants may also have had experience playing miniature golf, which may have aided their performance. Golf putting studies involving inexperienced or novice participants would benefit from an initial performance test to determine if participants within the same group are actually similar in skill level. While the limitations of the present study are acknowledged, the significant findings related to postural sway, HR, and HRV while putting in experienced and inexperienced golfers are encouraging.

## V. Conclusions

The successful putting stroke requires precisely controlled and coordinated movements. During the golf putting motion, the performer is in a relatively stable, upright position. These characteristics make the putting motion an ideal candidate for measuring postural sway and cardiovascular responses during performance. Using the EC approach, the present study examined changes in postural sway, HR, and HRV in participants performing in competitive situations.

Two separate experiments produced a competitive golf putting environment through the use of a monetary reward along with the condition of putting in front of a small audience. Results found across both experiments produced the following conclusions:

- 1) Postural sway in experienced as well as inexperienced golfers was reduced to facilitate golf putting performance in a more competitive situation;
- 2) Postural sway variability had a stronger influence on performance than HR and HRV for both golfers and beginners; and
- 3) Cardiovascular measures such as HR and HRV can be used to assess arousal and predict performance in participants during golf putting as long as the environment is competitive enough to induce a relatively high degree of performance pressure.

Further research in this area will show if these findings extend to more competitive golf putting situations as well as other areas of motor skill performance. High pressure situations with larger sample sizes should produce more significant results. Other biological factors such as respiration, muscle activity, and visual search strategies during the putting motion could also be explored.

Comparisons made between experienced and inexperienced golfers showed that experienced golfers took more time to attempt putts, exhibited more postural sway, and had higher HR and lower HRV than inexperienced players while putting. While these contrasts are supported by a wealth of research that has demonstrated differences between performers of different skill levels, the findings are limited by the fact that Experiments 1 and 2 studied different populations and did not follow identical procedures or take place in identical environments. Additional study is needed to explore and build on these findings. Future research concerning participants of varying skill level would benefit from having all participants perform the same task (or tasks) in the same environment. More field studies would also be advantageous, as they would involve situations more similar to true performance events.

Research studies related to golf putting performance under pressure have analyzed many factors, but the present study is the first to simultaneously measure postural sway variability, HR, and HRV in performers during the actual putting motion in a competitive environment. This study also benefited from the inclusion of both experienced and inexperienced golfers. EC theory has not yet been widely applied to the study of motor skill performance, but research concerning the performance of motor skills in a pressure-filled environment should be guided by an approach that considers multiple aspects of the person-environment relationship along with individual, environmental, and task constraints. Impaired golf putting performance under pressure is a multidimensional issue, and the present research was designed to assess various factors related to this subject. Future study in the motor skill performance domain would benefit from a similar approach.

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## **Appendix A**

### **CONSENT FORM**

#### **EFFECTS OF ANXIETY ON PERFORMANCE, POSTURAL SWAY, AND HEART RATE VARIABILITY WHILE GOLF PUTTING**

You are invited to be in a research study on the relationship between physiological and kinematic measures of the body and golf putting performance in a competitive tournament format. You were selected as a possible participant because you are a member of a golf team or club or are a student in a golf class. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by: Sam Haag, Graduate Student – Department of Kinesiology

#### **Background Information**

The purpose of this study is: To measure postural sway and heart rate variability and to observe putting motion during a golf putting tournament, and to determine how these measures relate to golf putting performance in golfers of varying skill levels in a competitive setting. In an attempt to encourage competition and increase performance anxiety, the person with the best final round score from each skill level group will be awarded a gift card at the end of the study. If you should make it to the final round, you will be asked to putt in front of an audience of other participants. The purpose of this technique is to further increase performance anxiety in the final round.

#### **Procedures:**

If you agree to be in this study, we would ask you to do the following things:

While wearing a heart rate monitor and standing on a force plate, perform 15 golf putts in 2 to 3 separate trials in a tournament-style format. Your performance in the first trial will not be used for tournament scoring, but the second trial will count for the tournament. Depending on your score in the second trial, you may be asked to perform a third trial, which will be the final round of the tournament. Testing will be completed on two to three different days and should take about 15 to 20 minutes each day.

#### **Risks and Benefits of being in the Study**

The study has a minimal amount of risk. Golf putting is not a strenuous physical activity, and the measuring devices are not invasive.

The benefits to participation are: You may learn how to cope with performance anxiety while putting in golf.

**Compensation:**

We thank you for your participation in this study. If you make it to the final round, you may have the chance to win a \$100 gift card if you have the best final round performance.

**Confidentiality:**

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject. Research records will be stored securely and only researchers in this study will have access to the records.

**Voluntary Nature of the Study:**

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

**Contacts and Questions:**

The researcher conducting this study is: Sam Haag. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact him at haag0033@umn.edu. You may also contact the student's advisor: Michael Wade, (612) 626-2094, mwade@umn.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact the Research Subjects' Advocate Line, University of Minnesota Medical Center, Fairview Riverside Campus, 2200 Riverside Avenue, Minneapolis, MN 55454.

*You will be given a copy of this information to keep for your records.*

**Statement of Consent:**

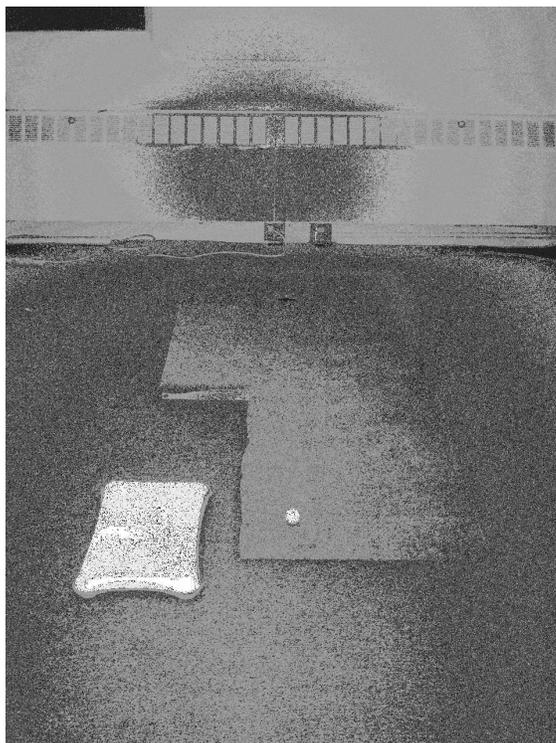
I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

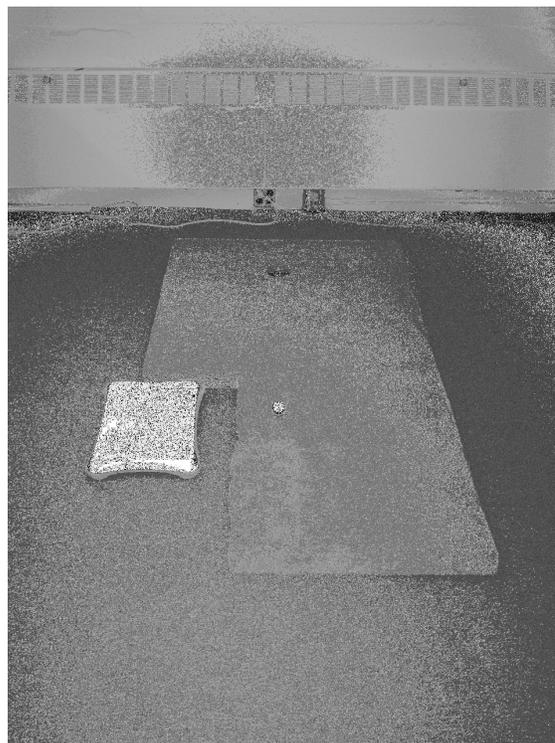
Signature of Investigator: \_\_\_\_\_ Date: \_\_\_\_\_

**Appendix B**

**Experiment 2 Putting Conditions**



Long Putt – 5.5 feet



Short Putt – 3.5 feet

### Appendix C

#### Sport Grid-Revised

Athletes experience a variety of thoughts and feelings before and during competitions. The Sport Grid-R allows you to describe some of these thoughts and feelings. The instructions for completing the grid are as follows:

1. Put an X in the box that indicates *both* the degree to which your body feels activated and the extent to which you are worried about your individual performance.

Top to bottom, the grid measures how activated or “pumped-up” your body feels – regardless of whether the feeling is positive or negative. The higher you go on the grid, the more activated your body feels.

Left to right, the grid measures how worried you are about your performance in the upcoming event. The further right you go, the more worried about your individual performance you are.

Very High Activation  
(Very “Pumped-up”)


Not  
Worried

Very  
Worried

Very Low Activation  
(Very Flat or Sluggish)

## Appendix D

### Experiment 1 Results

Table D1

#### *Abbreviations for Experiment 1 Variables*

Abbreviation	Measure
PuttError	Putting performance – mean distance of ball (cm) from hole across putts within round
MLPre	Baseline ML sway – standard deviation of medial-lateral COP movement during one minute of normal stance
MLPutt	ML sway while putting – mean of standard deviations of medial-lateral COP values across all putts within round
APPre	Baseline AP sway – standard deviation of anterior-posterior COP movement during one minute of normal stance
APPutt	AP sway while putting – mean of standard deviations of anterior-posterior COP values across all putts within round
HRPre	Baseline HR – mean heart rate (bpm) during two minutes of normal stance
HRPutt	HR while putting – mean heart rate (bpm) measured continuously across putting trials within round
HRVPre	Baseline HRV – heart rate variability (sample entropy) during one minute of normal stance
HRVPutt	HRV while putting – heart rate variability (sample entropy) measured continuously across putting trials within round
TimePutt	Mean putting time (seconds from “go” signal to contact with ball) across all putts within round

Table D2

#### *Putting time and putting performance in Rounds 1 and 2 in Experiment 1*

Measure	n <sup>†</sup>	Round 1 Mean (SD)	Round 2 Mean (SD)	t (df)	p	Effect Size <i>d</i>
TimePutt	14	4.67 (1.87)	3.80 (1.06)	2.42 (13)	.03*	0.57
PuttError	15	18.0 (8.0)	16.5 (8.5)	0.49 (14)	.63	0.18

<sup>†</sup> Putting time measures were unavailable for one participant in Round 2

Table D3

*Putting time and putting performance Across Rounds 1, 2, and 3 in Experiment 1*

Measure	n†	Round 1 Mean (SD)	Round 2 Mean (SD)	Round 3 Mean (SD)	F (df)	p
TimePutt	6	5.15 (2.64)	3.86 (1.42)	4.30 (1.75)	2.08 (2, 10)	.18
PuttError	7	14.2 (7.4)	11.1 (5.3)	46.7 (21.0)	16.89 (2, 12)	.00*

† Putting time measures were unavailable for one participant in Round 2

Table D4

*Pairwise Comparisons of Putting Performance Across Rounds 1, 2, and 3 in Experiment 1*

Measure	Rounds	Mean (SD)	p	Effect Size <i>d</i>
PuttError n = 7	1, 2	14.2 (7.4), 11.1 (5.3)	1.000	0.48
	1, 3	14.2 (7.4), 46.7 (21.0)	.005*	-2.06
	2, 3	11.1 (5.3), 46.7 (21.0)	.024	-2.32

\*p<.017 (Bonferroni adjustment, .05/3)

Table D5

*Correlations Between Round 3 Dependent Variables in Experiment 1 (n=7)*

Variable	1	2	3	4	5	6
1. PuttError	-	-.41	-.33	-.03	.29	-.18
2. TimePutt		-	.84*	.58	.25	.07
3. MLPutt			-	.47	.33	.15
4. APPutt				-	.03	.07
5. HRPutt					-	-.51
6. HRVPutt						-

\* p < .05

## Appendix E

### Experiment 2 Results

Table E1

#### *Abbreviations for Experiment 2 Variables*

Abbreviation	Measure
LongPuttE	Mean distance of ball (cm) from hole across long putts within round
ShortPuttE	Mean distance of ball (cm) from hole across short putts within round
MLPre	Baseline ML sway – standard deviation of medial-lateral COP movement during one minute of normal stance
MLLong	Mean of standard deviations of medial-lateral COP values across long putts within round
MLShort	Mean of standard deviations of medial-lateral COP values across short putts within round
APPre	Baseline AP sway – standard deviation of anterior-posterior COP movement during one minute of normal stance
APLong	Mean of standard deviations of anterior-posterior COP values across long putts within round
APShort	Mean of standard deviations of anterior-posterior COP values across short putts within round
HRPre	Baseline HR – mean heart rate (bpm) during two minutes of normal stance
HRLong	Mean heart rate (bpm) measured continuously across long putting trials within round
HRShort	Mean heart rate (bpm) measured continuously across short putting trials within round
HRVPre	Baseline HRV – heart rate variability (sample entropy) during one minute of normal stance
HRVLong	Heart rate variability (sample entropy) measured continuously across long putting trials within round
HRVShort	Heart rate variability (sample entropy) measured continuously across short putting trials within round
TimeLong	Mean putting time (seconds from “go” signal to contact with ball) across long putts within round
TimeShort	Mean putting time (seconds from “go” signal to contact with ball) across short putts within round
Worry	Degree of worry indicated on SGR prior to putting, ranges from 1-9
Activation	Degree of activation indicated on SGR prior to putting, ranges from 1-9

Table E2

*Within-subject Comparisons of Preperformance Variables for All Participants (n=20) and Finalists (n=8) in Rounds 1, 2, and 3 in Experiment 2*

Measure	Participants	Round 1 Mean (SD)	Round 2 Mean (SD)	Round 3 Mean (SD)	t/F <sup>†</sup> (df)	p	Effect Size <i>d</i>
MLPre	All	0.11 (0.40)	0.13 (0.07)		-2.12 (19)	.047*	-0.07
	Finalists	0.11 (0.04)	0.14 (0.06)	0.15 (0.06)	1.88 (2, 14)	.190	
APPre	All	0.82 (0.25)	1.04 (0.63)		-2.10 (19)	.050*	-0.46
	Finalists	0.97 (0.28)	1.28 (0.91)	1.32 (0.70)	1.81 (2, 14)	.199	
HRPre	All	85.4 (14.1)	82.4 (11.2)		0.93 (19)	.362	0.24
	Finalists	91.9 (18.7)	87.7 (12.3)	95.3 (15.1)	0.89 (2, 14)	.434	
HRVPre	All	1.19 (0.38)	1.21 (0.42)		-0.16 (19)	.878	-0.05
	Finalists	0.99 (0.36)	1.05 (0.45)	0.81 (0.39)	0.98 (2, 14)	.399	
Worry	All	2.9 (1.5)	3.0 (1.4)			.491	0.07
	Finalists	3.4 (1.9)	3.4 (1.5)	3.6 (2.1)	0.11 (2, 14)	.896	
Activation	All	5.3 (1.4)	5.2 (1.5)			.829	0.07
	Finalists	5.7 (1.4)	5.3 (1.7)	5.2 (2.0)	0.59 (2, 14)	.569	

\*  $p < .05$

† t-statistics refer to comparisons made within all participants in Rounds 1 and 2, F-statistics refer to comparisons made within final round participants across all three rounds

Note. t-statistics were not available for Wilcoxon-signed rank tests used to compare Worry and Activation within all participants in Rounds 1 and 2

Table E3

*Performance Variables and Effect Sizes for All Participants (n=20) in Rounds 1 and 2 in Experiment 2*

Measure	Round 1 Mean (SD)	Round 2 Mean (SD)	Effect Size <i>d</i> for Round
MLLong	0.39 (0.23)	0.39 (0.20)	0.00
MLShort	0.36 (0.16)	0.37 (0.18)	-0.06
Effect Size <i>d</i> for Task	0.15	0.11	
APLong	0.97 (0.39)	1.12 (0.64)	-0.28
APShort	1.00 (0.52)	1.05 (0.69)	-0.08
Effect Size <i>d</i> for Task	-0.07	0.11	
HRLong	87.5 (10.7)	87.9 (10.3)	-0.04
HRShort	87.1 (10.7)	86.5 (9.2)	0.06
Effect Size <i>d</i> for Task	0.04	0.14	
HRVLong	1.19 (0.31)	1.16 (0.28)	0.11
HRVShort	1.14 (0.36)	1.21 (0.33)	-0.20
Effect Size <i>d</i> for Task	0.15	-0.16	
TimeLong	2.52 (0.97)	2.65 (0.99)	-0.13
TimeShort	2.25 (0.63)	2.25 (0.66)	0.00
Effect Size <i>d</i> for Task	0.33	0.48	
LongPuttE	18.5 (13.6)	14.0 (11.8)	0.35
ShortPuttE	9.8 (7.6)	3.8 (5.8)	0.89
Effect Size <i>d</i> for Task	0.79	1.10	

Note. Effect sizes for task are within round, effect sizes for round are within each putting task measure. Results of statistical tests comparing these variables are provided in the text.

Table E4

*Putting Time and Putting Performance for Finalists (n=8) in Rounds 1, 2, and 3 in Experiment 2*

Measure	Round 1 Mean (SD)	Round 2 Mean (SD)	Round 3 Mean (SD)
TimeLong	2.85 (1.22)	2.53 (0.99)	2.77 (1.09)
TimeShort	2.45 (0.57)	2.22 (0.62)	2.41 (0.95)
LongPuttE	12.6 (8.4)	3.5 (2.3)	4.3 (5.3)
ShortPuttE	7.7 (3.7)	1.5 (2.9)	4.8 (9.6)

Note. Results of statistical tests comparing these variables are provided in the text

Table E5

*Pairwise Comparisons of Putting Error During Long Putt and Short Putt Performance Across Rounds 1, 2, and 3 in Experiment 1*

Measure	Rounds	Mean (SD)	p	Effect Size <i>d</i>	
LongPuttE	1, 2	12.6 (8.4), 3.5 (2.6)	.052	1.46	
	n = 8	1, 3	12.6 (8.4), 4.3 (5.3)	.152	1.18
		2, 3	3.5 (2.6), 4.3 (5.3)	1.000	-0.19
ShortPuttE	1, 2	7.7 (3.7), 1.5 (2.9)	.019	1.87	
	n = 8	1, 3	7.7 (3.7), 4.8 (9.6)	1.000	0.40
		2, 3	1.5 (2.9), 4.8 (9.6)	1.000	-0.47

Note. Statistical significance if  $p < .017$  (Bonferroni adjustment,  $.05/3$ )

Table E6

*Correlations Between Round 1 Dependent Variables in Experiment 2 (n=20)*

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. LongPuttE	-	.42	-.15	-.33	-.15	.40	-.09	.02	.01	.06	.23	-.24	-.02	.07	-.04	.19	-.07	.26
2. ShortPuttE		-	.09	-.30	-.05	.27	-.11	-.32	.02	-.12	.15	-.26	.03	-.04	-.04	-.19	-.05	-.18
3. MLPre			-	.27	.37	-.41	-.36	-.16	-.15	-.28	.08	.28	.05	.16	.17	-.36	.28	-.57*
4. APPre				-	.21	.05	-.17	.21	.26	.08	-.13	.30	-.12	.20	.11	.28	.14	.09
5. HRPre					-	-.68*	.02	.20	-.08	-.08	-.05	-.19	-.05	.11	.80*	-.60*	.88*	-.52*
6. HRVPre						-	-.17	-.17	.08	.00	.16	.11	.08	.09	-.32	.50*	-.42	.46*
7. Worry							-	.17	-.10	.08	-.32	-.59*	-.32	-.38	-.04	.06	-.01	.21
8. Active								-	.01	.02	.21	.13	.22	.23	.27	-.01	.25	.14
9. TimeLong									-	.80*	-.38	-.19	-.41	-.45*	-.24	.51*	-.25	.33
10. TimeShort										-	-.53*	-.40	-.58*	-.48*	-.21	.32	-.22	.21
11. MLLong											-	.56*	.83*	.80*	.15	.00	.13	.17
12. APLong												-	.61*	.69*	-.10	.11	-.13	.07
13. MLShort													-	.68*	.25	-.15	.20	.01
14. APSShort														-	.31	-.16	.28	.00
15. HRLong															-	-.65*	.97*	-.50*
16. HRVLong																-	-.66*	.90*
17. HRShort																	-	-.51*
18. HRVShort																		-

\* p &lt; .05

Table E7

*Correlations Between Round 2 Dependent Variables in Experiment 2 (n=20)*

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. LongPuttE	-	.41	.04	-.12	-.25	.28	-.37	-.12	-.07	-.17	.45*	.47*	.16	.50*	-.11	.26	-.10	.29
2. ShortPuttE		-	-.08	-.01	-.27	.08	.04	.05	-.05	-.22	.34	.35	.29	.43	-.29	.24	-.39	.45*
3. MLPre			-	.41	.10	-.06	-.10	.04	-.43	-.31	-.03	.18	-.15	.16	.29	-.21	.28	-.34
4. APPre				-	.52*	-.18	-.18	.34	.11	.09	-.12	-.04	-.01	-.04	.54*	-.22	.51*	-.15
5. HRPre					-	-.72*	-.01	.29	.06	.01	-.01	.08	-.03	.01	.85*	-.43	.87*	-.42
6. HRVPre						-	-.10	-.23	.03	.06	.12	-.02	.06	.01	-.54*	.60*	-.53*	.31
7. Worry							-	.43	.11	.10	-.26	-.21	-.28	-.29	-.07	.13	-.12	.06
8. Active								-	.06	.07	.20	.05	.14	.10	.46*	-.07	.32	.32
9. TimeLong									-	.89*	-.33	-.35	-.26	-.32	-.12	.22	-.04	.18
10. TimeShort										-	-.32	-.33	-.27	-.34	-.20	.26	-.10	.14
11. MLLong											-	.72*	.80*	.65*	.10	.17	.10	.26
12. APLong												-	.51*	.94*	.10	-.13	.14	.01
13. MLShort													-	.48*	-.02	.15	.04	.38
14. APShort														-	.05	-.12	.06	.00
15. HRLong															-	-.45*	.95*	-.50*
16. HRVLong																-	-.37	.68*
17. HRShort																	-	-.49*
18. HRVShort																		-

\* p &lt; .05

Table E8

*Correlations Between Round 3 Dependent Variables in Experiment 2 (n=8)*

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. LongPuttE	-	-.05	-.24	-.49	.38	-.51	-.13	-.73*	-.19	-.27	-.38	-.46	-.24	-.42	-.20	-.09	-.33	-.10
2. ShortPuttE		-	.09	-.31	.26	.04	-.04	.19	.61	.42	-.09	.23	-.01	-.23	-.26	.65	-.31	.50
3. MLPre			-	.40	-.08	-.18	-.47	.01	.09	.04	-.28	-.13	-.20	.53	.18	-.43	-.09	-.04
4. APPre				-	-.05	.38	-.33	.49	.12	.32	-.26	.07	-.11	.55	.33	-.19	.38	-.04
5. HRPre					-	.25	.41	.28	-.05	-.16	-.18	.19	-.15	.13	.62	-.15	.55	-.48
6. HRVPre						-	-.28	.48	.52	.69	.51	.45	.57	.40	-.13	.17	.09	.01
7. Worry							-	.41	-.38	-.47	.28	.27	-.07	-.40	.51	-.02	.64	-.37
8. Active								-	.35	.38	.19	.44	.02	.15	.49	.05	.68	-.20
9. TimeLong									-	.96*	-.20	-.17	-.18	-.21	-.51	.41	-.37	.41
10. TimeShort										-	-.14	-.11	-.07	-.05	-.48	.37	-.30	.38
11. MLLong											-	.73*	.87*	.39	.19	-.10	.26	-.36
12. APLong												-	.81*	.56	.48	.18	.48	-.18
13. MLShort													-	.61	.12	.05	.11	-.18
14. APSShort														-	.42	-.37	.27	-.28
15. HRLong															-	-.53	.92*	-.73*
16. HRVLong																-	-.40	.84*
17. HRShort																	-	-.69
18. HRVShort																		-

\* p &lt; .05