THE EFFECTS OF ATTENTIONAL FOCUS ON PERFORMANCE, NEUROPHYSIOLOGICAL ACTIVITY AND KINEMATICS IN A GOLF PUTTING TASK

BY

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Abstract

Impaired performance while executing a motor task is attributed to a disruption of normal automatic processes when an internal focus of attention is used (Wulf, McNevin, & Shea, 2001). When an external focus of attention is adopted, automaticity is not constrained and improved performance is noted. What remains unclear is whether the specificity of internally focused task instructions may impact task performance. In the present study, behavioural, kinematic and neurophysiological outcome measures assessed the implications of changing attentional focus for novice and skilled performers in a golf putting task. Findings provided evidence that when novice participants used an internal focus of attention related to task execution, accuracy, kinematics of the putter, and variability of EMG activity in the upper extremity were all adversely affected as task difficulty increased. Instructions which were internal but anatomically distal to the primary movement during the task appeared to have an effect similar to an external focus of attention and did not adversely affect outcomes.

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Introduction

The effects of attentional focus while performing motor tasks is an emerging subject of research in the field of motor learning (Wulf, 2007). A large amount of anecdotal evidence suggests that "self-attention" while performing a motor skill can disrupt performance, especially with a skill that is well-practiced and familiar (Wulf, Höß, & Prinz, 1998). However, the amount of experimental evidence supporting the effects of attentional focus is limited in comparison to anecdotal accounts.

James (1950) was one of the first to examine the differential effects of focusing on one's own body or on the surrounding environment while performing a task. Effects on performance were initially described in terms of being either close or remote. Close effects referred to the kinesthetic feedback available to the individual and the consequences directly related to performing a motor skill. Remote effects referred to the distant results of an action, and were often more important than the actual movement. Several years later, Henry and Rogers (1960) developed a memory drum theory which supported the findings of James (1950). In their theory, Henry and Rogers (1960) hypothesized that consciously controling movements should interfere with normal performance of a task. Focusing on a movement that is to be performed should produce an increase in reaction time. Conversely, when the focus is on the stimulus that evokes the response, less interference should result and reaction time should decrease. Further studies by Henry (1960) and Christina (1973) provided support for previous work on attentional focus and led to the development of numerous experiments attempting to validate the anecdotal evidence on the subject.

According to a review by Wulf (2013), numerous studies over the past 16 years have demonstrated that the location of the focus of attention is critical to the outcome of skill execution. An internal focus of attention is defined as instructions or feedback that relate directly to an individual's own body movements, while an external focus of attention relates to the effects of those movements on the environment or the apparatus being used (Wulf et al., 1998). Manipulating attentional focus through task instruction in both neutral (McNevin, Shea, & Wulf, 2003; Wulf et al., 1998) and sport-specific tasks (Perkins-Ceccato, Passmore, & Lee, 2003; Zachry, Wulf, Mercer, & Bezodis, 2005) as well as through participant feedback (Shea & Wulf, 1999; Wulf, McConnel, Gärtner, & Schwarz, 2002) is demonstrated in the literature. It has been well established that adopting an external focus of attention leads to improved performance and learning relative to an internal focus. The comparison between location of attentional foci has since become the basis for numerous experiments investigating the effects of varying task instructions.

The direct comparison between internally and externally focused task instructions has been well examined in the literature (Wulf, 2007). However, only a small number of studies have examined variations of the same type of attentional focus on their own. McNevin et al. (2003) conducted an experiment where participants balanced on a stabilometer while focusing on one of three locations. Trials were completed with the focus on the feet (internal), a marker on the platform close to their feet (external proximal) and a marker further away from the feet on the platform (external distal). Two recent studies have investigated sport-specific comparisons of externally focused task instructions. A dart throwing study by McKay and Wulf (2012) compared both preference of task instructions and performance when novice participants focused on either the flight of the dart (external proximal) or the bulls-eye (external distal). Porter, Anton and Wu (2012) used a standing long jump task to examine performance effects between focusing past the starting line (external proximal) and focusing on a target three meters away from the starting line (external distal). In all cases, instructions using an external focus of attention that was distal to the actual task being executed demonstrated improved performance relative to instructions that were proximal in nature. To date there is a paucity of published work investigating the effects of multiple internal foci of attention that are proximal or distal to the main movements involved in the task.

Previous attentional focus research includes a limited number of studies investigating surface electromyography (EMG) (Vance, Wulf, Tollner, McNevin, & Mercer, 2004; Zachry et al., 2005) and movement kinematics (Wulf & Dufek, 2009; Zentgraf & Munzert, 2009) as dependent measures. EMG activity denotes myoelectric signals in a muscle of interest and is influenced by the recruitment of motor unit action potentials and their firing frequency (Konrad, 2005). Kinematic analysis provides a quantitative description of a movement in terms of changes to spatial position or changes in speed (Magill, 2007). Examining "production measures" such as EMG and kinematic activity provides insight into how the motor system is affected in its approach to muscular activity and movement when the focus of attention is altered (Zachry et al., 2005). Even fewer studies have explored the effect that varying task instructions may have on performance measures such as accuracy while also examining EMG and kinematic effects (Lohse, Sherwood & Healy, 2010). It is imperative that future attentional focus research prioritizes the investigation of underlying physiological and kinematic activity in addition to performance outcome changes. Combining these three outcome measures will allow for a more robust understanding of what is occurring within the human body when attentional focus is altered and the subsequent implications on performance.

The aim of the current study was to combine standard approaches used to examine the effects of manipulating attentional focus with the addition of novel experimental design elements. A previous dart throwing study by Lohse et al. (2010) examined the effects of attentional focus by combining a triad of outcomes measuring performance, physiological and kinematic effects. The current study attempted to replicate the experimental design of Lohse et al. (2010) by using a golf putting task, with alterations to the attentional focus conditions provided to participants. Among the three sets of task instructions were two that were internally focused, relating to either the golf putting movement (anatomically proximal) or the stance (anatomically distal). The inclusion of multiple internally focused task instructions provided insight into the specific effects that an internal focus has on both performance and underlying changes to the motor system. These effects were further examined to determine whether they were localized to the task being performed or if they were generalized to the whole body.

Review of Literature

Early Laboratory Experiments

Weigelt and Wulf (1997) were among the first to quantify the potential significance of attentional focus during task execution. In their experiments, participants were instructed to use a ski simulator to produce movements of maximum amplitude and frequency. In the first experiment half of the participants were given instruction on the optimal timing of force application during the practice session. The other half of participants were not given any instruction. In the second experiment, half of the participants were given the same instructions regarding the timing of force application after the retention task, while the other half were given no instruction. Results from both experiments revealed a drop in performance after instructions were provided, indicating that instructions that are intended to enhance learning may be detrimental to performance. These results were in line with findings of previous implicit learning literature (Berry & Broadbent, 1988; Green & Flowers, 1991; Reber, 1976) suggesting that instructions focusing on the details of a task may be degrading to learning compared to receiving no background information. However, it remained unclear from the findings of Weigelt and Wulf (1997) what specific conditions produced the decrease in learning and performance.

Subsequent studies by Wulf and colleagues (Wulf et al., 1998; Shea & Wulf, 1999; Wulf, Shea, & Park, 2001; Wulf et al., 2001) investigated the role that task instruction and attentional focus had on performing complex motor tasks. In these studies, participants balanced on a stabilometer with the goal of maintaining a horizontal alignment. Participants in Wulf's seminal study (Wulf et al., 1998, Experiment 2) were instructed to either focus on their feet (an internal focus of attention) or on markers on the platform (an extenal focus of attention). A control group was not provided with any instructions. Following two days of practice, all particpants performed a retention test using the same task instructions they had practiced with. The externally focused task instructions enhanced learning on the retention task, while the internally focused instructions were no more effective than balancing with no instructions at all. Wulf et al. (1998) concluded that consciously controlling movement, such as what is done when utilizing an internal focus of attention, may interfere with automatic motor control processes. These conclusions parallelled the work of Henry (1953) in a task that involved holding the position of a lever constant. Participants exerting conscious control over the lever found their performance was hampered when they focused on maintaining constant pressure on the lever as opposed to maintaining a static position. The results found by Wulf et al. (1998) in the stabilometer tasks further validated the learning advantages associated with externally focused task instructions.

Experiments Involving Sports Skills

Experiments utilizing laboratory tasks such as balancing on a stabilometer quickly evolved into testing more complex motor tasks such as sports skills. A golf pitching study by Wulf, Lauterbach and Toole (1999) was one of the initial experiments to investigate the effects of attentional focus in a non-laboratory setting. In the experiment, participants pitched golf balls to a target 15 metres away from the starting point. The two groups of participants were then provided with slightly different task instructions relating to their swing. The group given internal focus instructions was asked to concentrate on the swinging motion of their arms while they swung the club. The external focus group was asked to focus on creating a pendulum-like motion with the golf club. Participants utilizing the externally focused task instructions performed with greater accuracy in practice as well as in a delayed retention test without instruction.

An experiment investigating tennis forehand strokes by Wulf, McNevin, Fuchs, Ritter and Toole (2000, Experiment 1) provided further support for improved performance when utilizing an external focus of attention. Wulf and colleagues (2000) investigated whether it was more advantageous to focus on the effects of a movement compared with directing attention to an unrelated external cue. Unskilled tennis players were divided into two groups and were instructed to hit a tennis ball to a target on the other side of the court. One group was instructed to focus on the ball as it approached the racquet and the other had instructions to focus on the ball as it left the racquet. Both groups were given task instructions with an external focus, however the results demonstrated that focusing on the effect of the movement (the path of the ball after it hit the racquet) produced increased shot accuracy in a retention task. Although this study provided further support for an external focus of attention in a complex motor task, it also demonstrated that careful thought must be given to the wording of task instructions as similar statements may produce different results.

Constrained Action Hypothesis

Following the converging results of previous studies demonstrating increased performance and learning with an external focus of attention (Wulf, 2007), researchers looked to Prinz's common coding theory (Prinz, 1997) to explain the results. Prinz's theory states that perception and action share a common representational domain in the brain and do not require separate translation. Actions are planned proportionally in terms of their effects and are continuous with ongoing events. The common platform allows certain products of both perception and action to be shared. In the case of the experiments by Wulf and colleagues (Wulf, 2007), actions should be more successful when planned in terms of movement effects, perhaps with a connection to externally focused task instructions. However, Prinz's theory was fairly abstract, and was not able to explain the varied learning effects that were key to understanding differences in attentional focus (Wulf & Prinz, 2001).

In an attempt to explain the benefits of an external focus of attention relative to an internal focus beyond the common coding theory, Wulf and colleagues (Wulf et al., 2001; Wulf & Prinz, 2001) developed the constrained action hypothesis. When focusing on their own body performing an action (an internal focus of attention), individuals may override the automatic processes that would otherwise take control of the movement. The override may cause coordination to be disrupted and any automatic reflexes to be negatively impacted. Focusing on the movement effect (an external focus) allows the motor system to perform the skill with more automaticity, and thus an increase in performance and learning is possible. Although there is a necessary balance between conscious processing and automaticity, the original experiments altering the focus of attention demonstrate a preference toward task instructions favouring automatic processes (Wulf et al., 2001).

Relative Distance of Focus of Attention

Results obtained from earlier studies provide evidence that increasing the distance of the external focus relative to the location of task execution may further increase the benefits of an external focus of attention (Wulf & Prinz, 2001). Based on this suggestion, McNevin et al. (2003) used a subsequent stabilometer task to investigate performance and learning effects while varying the distance of the target of the external focus of attention. It was hypothesized that an external focus of attention close to the body resembles an internal focus, and thus may lose its benefits when completing the balance task. Thus, an external focus condition too proximal could produce similar results to the internal focus condition. In the experiment, McNevin et al. (2003) utilized four experimental conditions relating to attentional focus. Participants in the internal focus condition were instructed to keep their feet level on the stabilometer. Particpants in the three external focus conditions were asked to fixate on markers placed on the platform either directly in front of their feet, to the outside of their feet (far outside) or between the feet (far inside). The participants focusing on the far otuside markers were most effective in maintaining balance on a retention test relative to those focusing on markers close to their body. These findings provided preliminary evidence that focusing attention further away from one's body may be beneficial to learning and performance because it is easier for the body to distinguish that focus from the body's own movements. However, McNevin et al. (2003) did not alter the distance of the focus of attention in this study, and questions remained about the optimal distance for an external focus of attention to produce favorable outcomes.

To investigate appropriate parameters for an exernal focus of attention, Wulf et al. (2000) had participants hit golf balls to a target 15 metres away using a 9 iron while employing varying degrees of external focus. Participants adopted either a distal focus of attention, (the anticipated trajectory of the golf ball and the target) or a proximal focus, (the motion of the club). Results indicated that the relatively large distance between the action and the distal focus was too great to demonstrate the benefits associated with an external focus of attention. Participants who focused on the kinematics of the golf club performed with increased accuracy across both practice and retention tasks, demonstrating that there may be a limit to the positive effects of an external focus. Future investigation into an ideal distance for an external focus of attention in various motor activities is still needed (Wulf & Prinz, 2001), as it has not been studied in the literature beyond the work by McNevin et al. (2003).

A more recent study by McKay and Wulf (2012) has looked at outcomes related to distal and proximal external foci of attention. In their study, novice participants were instructed to complete a dart throwing task and use either a proximal external focus of atttention (the flight of the dart) or a distal external focus (the target). After completeing trials using both conditions, participants were asked to select their preferred set of focus instructions. The distal focus of attention produced improved accuracy and was also the preferred set of focus instructions among participants. Porter, Anton and Wu (2012) conducted a standing long jump experiment with a similar experimental design. Participants were asked to perform two jumps using two external focus conditions- proximal external (using the starting line as the reference) and external distal (using a cone placed 3m distal to the starting line as a reference). Two jumps were also completed using a control condition (jump as far as possible). The authors found that the distal external focus condition produced significantly greater jump distances compared to the other two conditions, replicating the findings of McKay and Wulf (2012). Overall there are consistent results favoring a distal exernal focus of attention compared to those that are externally proximal. However, there is a gap in the current literature concerning the effects of varying internal foci of attention related to distance and location. It is unknown whether altering the location of internally focused task instructions may produce effects similar to those achieved with an external focus of attention. The nature of the task, the location of the foci relative to the task and the skill level of the individual executing the task are all variables which may play a role in the outcomes associated with changing focus of attention.

Participant Skill Level

Another variable which may alter the effects of attentional focus is an individual's skill level in executing a specific task. One of the initial studies to compare the performance of both a novice and skilled groups of participants was by Wulf et al. (2002, Experiment 1). Two groups of volleyball players (novice and skilled) were given feedback on their overhand serves with either an external or an internal focus. The results provided evidence of increased accuracy within practice trials and a retention test within the external focus feedback condition. However, this study utilized feedback as its method for determining differences in attentional focus in a complex motor skill, and not task instructions as in previous experiments. The difference in experimental design may have influenced the results of the study, and may not indicate differences between novice and skilled performers completing the same task.

A subsequent golf pitching study by Perkins-Ceccato et al. (2003) manipulated task instructions between two groups of golfers (high-skill and low-skill). Participants pitched a ball to one of four target distances under either internal or external focus instructions. Under the set of internal task instructions, participants were asked to focus on the form and force of their golf swing. With the external focus instructions, participants were asked to concentrate on pitching the ball as close to the target as possible. Participants performed 40 shots in each of the two focus conditions. Consistent with previous attentional focus findings, the results indicated that high-skill golfers performed with better accuracy under the external focus instructions compared to the internal focus instructions. In a skilled performer, the movement pattern required to perform the skill is considered automatic, allowing the performer to focus freely on external targets without a detriment to their performance. However, the same was not the case for the group of low-skilled golfers. Low-skilled participants performed with better accuracy with the internal focus task instructions, contrary to previous findings which predicted that an external focus produces improved performance and should be advantageous across all groups. The findings of this study are evidence that for novice performers who may not have developed the required degree of automaticity to perform a skill, attentional focus on their own body positioning may be more beneficial.

The results of the study by Perkins-Ceccato et al. (2003) are in line with the deautomization of skills hypothesis proposed by Masters (1992). The hypothesis predicts a decrement to performance when skilled performers are instructed to focus on the individual components of a skill, rather than the product or end goal. Results pertaining to the skilled performers are also consistent with the constrained action hypothesis (Wulf et al., 2001; Wulf & Prinz, 2001). Few studies have further investigated the support for an internal focus of attention as found by Perkins-Ceccato et al. (2003). In a baseball batting study, Castaneda and Gray (2007) found that highly skilled batters performed better when they focused their attention on the ball leaving the bat (an external focus) compared to low skilled batters who favoured focusing on any aspect of the swing (either external or internal foci). Wulf and Su (2007) compared the performance of beginner and expert golfers against control groups without attentional focus instructions in two separate experiments. Unfortunately, the two experiments were not combined and the three groups were not directly compared against each other, so it is difficult to intrepret whether the results of Perkins-Ceccato et al. (2003) were supported. It has yet to be demonstrated in the literature at exactly what point in an individual's training and experience does an external focus of attention begin to show benefits related to performance.

Neurophysiological Effects

Early literature on attentional focus is primarily behavioural in nature. Investigation of focus of attention during motor tasks has generally been outcome-based, and has concentrated on various measures of accuracy (Wulf et al, 2000; Wulf et al., 2002). There is a lack of published evidence involving other dependent measures including the possible neurophysiological effects associated with changing attentional focus. Vance et al. (2004) found that adopting an external focus of attention produces lower EMG readings in the agonist muscles required to execute a task relative to an internal focus. Participants in this experiment performed a biceps curl and were asked to focus either on the bar (external focus) or on their arms (internal focus). The external focus condition produced higher velocity movements around the elbow joint and resulted in decreased EMG activity in the upper extremities. Preference towards an external focus produced increased muscular efficiency and offered further support for the constrained action hypothesis. The decreased EMG activity resulted in a more effective recruitment of motor units and also supported the notion of automaticity within the motor system.

Although the findings by Vance et al. (2004) are critical in understanding the improved performance under an external focus of attention, the biceps curl task used by the experimenters was solely movement-based and did not have a measureable goal-oriented outcome. Zachry et al. (2005) used a basketball free throw task to investigate the link between an accuracy-based outcome measure and EMG activity of select muscles. Results indicated that free throw accuracy was higher when participants used an external focus of attention, and similar to the study by Vance et al. (2004), EMG activity of the shooting arm was reduced under the external focus condition. Thus, the benefits of an external focus of attention were supported by both accuracy and EMG dependent measures.

Kinematic Effects

In a review by Peh, Chow and Davids (2011), it was noted that more investigation was needed to examine the changes in kinematic and kinetic variables under varying attentional focus conditions. Few studies to date have investigated the effects that changing task instructions have on the motor system and coordination patterns. In a jump and reach task, Wulf, Zachry, Granados and Dufek (2007) concluded that jumpers utilizing an external focus of attention were able to increase their jump height. However, the study did not measure any variables beyond the performance outcome measure, and thus the study was lacking in a physiological explanation for the results. Two years later, Wulf and Dufek (2009) replicated the jump and reach study by Wulf, et al. (2007) and measured kinematic changes in the lower body using a Vicon motion capture system. The results indicated that jumpers under externally focused task instructions jumped higher by producing greater forces and increased joint moments in the lower body. The kinematic analysis of the lower body completed by Wulf and Dufek (2009) demonstrated that motor coordination is improved with an external focus of attention, and provided an alternative perspective to examining attentional focus. Analysis beyond performance outcomes provides key insight into the mechanism of changes affecting the performance and learning of a motor task.

Perhaps the best example of a study investigating performance outcomes in a motor task along with neurophysiological and kinematic effects was a dart throwing task by Lohse et al. (2010). Along with measuring accuracy of the dart throws, researchers also recorded EMG signals from the agonist (triceps brachii) and antagonist (biceps brachii) muscle groups during task execution. Videography was used to capture the participants' movements in the sagittal plane as they threw the dart. Kinematic variables that were measured included shoulder and elbow angles, throwing time and the angular velocity of the dart. The results of the dart throwing experiment indicated improved accuracy and reduced EMG activity in the agonist muscle group, replicating findings which had been previously reported (Vance et al., 2004; Zachry et al., 2005). With the inclusion of kinematic data, Lohse et al. (2010) were able to comment further on the changes in performance as a result of altering attentional focus. An increased variability in shoulder movement was the only kinematic measure to significantly change when participants adopted an external focus of attention. This increase in variability is similar to the functional variability that is exhibited by expert performers of any motor skill and leads to an overall improvement in movement economy. Lohse et al. (2010) reasoned that the variability in the end product of a motor task is smaller than the variability of the components used to complete the task, and the function of variability is to preserve the planned outcome. Thus, increased variability while completing a motor task may lead to improved movement economy and subsequently improved performance. This explanation supports the conclusions made by Wulf and Prinz (2001) regarding facilitation of compensatory variability while performing a motor task under external focus instructions. When these kinematic findings were taken into account with the reduced EMG activity in the agonist muscles, Lohse et al. (2010) concluded that an external focus of attention improved coordination by reducing muscular activity, which thus allowed for increased movement variability and produced improved movement economy.

In summary, while it is well documented that varying attentional focus leads to altered performance outcomes, there are few studies which have investigated the mechanisms behind those differences. Variations in the wording of task instructions involving multiple external foci of attention as well as their distance relative to the individual have found that there is a distance limit to the benefits of an external focus. However, it appears that no studies to date have investigated the performance effects of multiple internal focus instructions. The neurophysiological effects and kinematic changes that occur when task instructions are altered are imperative to understanding performance outcomes but few studies have investigated their contribution. Attentional focus has also been found to be affected by the skill level of the individual performing the motor task, a factor which is critical to understanding the effects of varying task instructions. The current study draws together many facets of previous attentional focus research into one experiment utilizing novice and skilled individuals performing a common motor skill, golf putting. Performance, neurophysiological and kinematic effects will be measured under three attentional focus conditions, with the novel inclusion of two that are internal in nature. The combination of these behavioural and physiological outcome measures will create a unique experimental design and contribute to the body of knowledge surrounding attentional focus research.

Objectives

Purpose

The purpose of this study was to examine the effects of changing the attentional focus instructions in a golf putting task performed by skilled and novice golfers. The first objective was to determine if performance outcomes (accuracy) were affected by changes to task instruction. The second was to determine if the neurophysiological activity (EMG) of selected upper and lower body muscles was differentially impacted by task instruction. The third objective was to determine if movement economy and kinematic activity was also affected by changes to task instruction.

Hypotheses

The primary hypothesis of this study was that skilled golfers would demonstrate improved putting accuracy, increased kinematic variability of their swing (which would lead to an improved movement economy) and reduced EMG activity of their extensor carpi radialis muscle (ECR), the agonist muscle in the upper extremity while putting when performing in the external focus condition. These results would be consistent with both the constrained action hypothesis and the deautomization of skills hypothesis. When looking specifically at novice golfers, it was predicted that they would demonstrate improved putting accuracy when performing in either of the internal focus conditions. It was also predicted that the novice golfers would demonstrate a decreased kinematic variability in their swing (leading to a decreased movement economy) and increased EMG activity in both of the target muscles when performing in any of the putting conditions.

A secondary hypothesis was that differences in EMG activity would be present between both internal focus conditions within both participant groups. It was predicted that when participants putted using the internal movement task instructions (focus on their hands gripping the club and the position of their elbows) they would produce increased EMG activity in the upper limb (ECR). When the internal stance task instructions were used (focus on weight being equally distributed through both feet), it was predicted that increased EMG activity would be produced in tibialis anterior (TA) in the lower limb. EMG results were used to demonstrate a potential localized physiological effect of task instruction unrelated to outcome or skill level, beyond a general whole body automaticity associated with an external focus of attention.

Method

Participants

Participants consisted of 11 novice golfers (4 male; age *M*=34.2, *SD*= 14.4) and 13 skilled golfers (12 male; age *M*=33.5, *SD*=13.2) recruited from the general public. To determine the minimum sample size, an a priori power calculation was performed for a desired statistical power level of 0.8, and an alpha set to 0.05. The power calculation utilized existing putting outcome means and standard deviations for similar population groups. In order to attain an appropriate power level, a minimum sample size of 9 participants per group was required. The novice golfers were tested between October and December 2013 and were required to self-report a handicap of 20 or higher, or play on average less than three rounds of golf per year. The skilled golfers were tested between February and April 2014 and were required to self-report a handicap of 8 or lower (Perkins-Ceccato et al., 2003). All participants had normal or corrected-to-normal vision and were required to putt right handed using a traditional grip. All participants were provided with an informed consent document (see Appendix) upon arrival to the testing facility in the Perceptual Motor Behaviour Laboratory (Bannatyne Campus) at the University of Manitoba. At this time participants were able to review the requirements for the study and had the opportunity to discuss any aspect of their participation. Ethics approval was obtained from the Health Research Ethics Board at the University of Manitoba prior to the commencement of testing.

Apparatus

Participants completed the putting task on a 6.7 m x 1.2 m section of synthetic grass (EZ-Grass, Calgary, Alberta) with a stimp reading of 9. The stimp reading is a measure of the speed of a putting green and is measured with a device called a stimpmeter. A stimpmeter is a 91.4 cm

(36 in) aluminum bar with a V-shaped groove down the middle. A golf ball is placed in a notch close to one end of the stimpmeter and when the stimpmeter is raised approximately 20 degrees off of the ground, the ball rolls out of the notch and on to the green (Roh & Lee, 2010). In the case of the putting surface used in this experiment, the ball rolled 2.7 m (9 ft) past the end of the stimpmeter, therefore the stimp reading was 9. The putting green was set upon a plywood platform of the same size and raised 10.5 cm off of the ground. The starting position of the ball for each trial was marked with a microswitch that was fixed to the plywood platform but protruded through the green. A reed switch was embedded in the platform immediately behind the microswitch to correspond with the starting position of the putter. A thin magnet was fixed to the underside of the putter to complete a circuit with the reed switch. A strip of light emitting diodes (LEDs) was embedded in the green to form the shape of a regulation golf hole (10.8 cm diameter) at distances of 3 m and 5 m (Gonzalez, Kegel, Ishikura & Lee, 2012) from the starting position of the ball. Only one target was illuminated at a time.

Figure 1. Diagram of Putting Apparatus

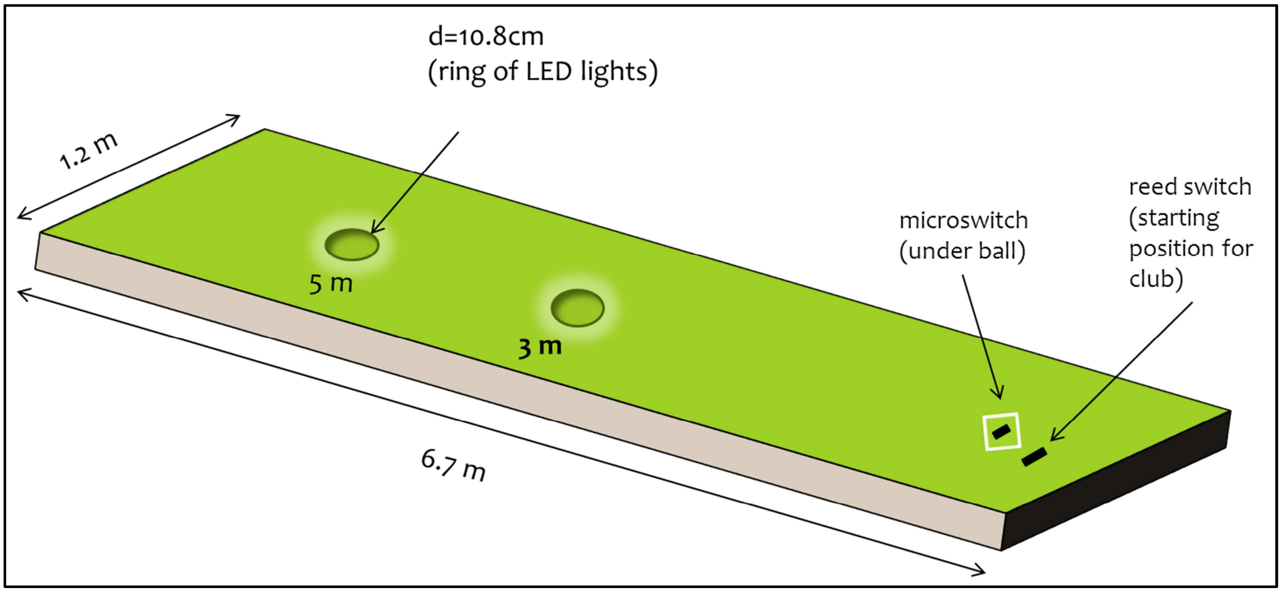

Figure 1. Schematic diagram of the putting platform used outlining dimensions and key elements related to data collection.

Instrumentation

All participants completed the putting task using a standardized club (Jazz Vector, Winnipeg, MB) provided by the principle investigator. During all trials, participants were required to wear PLATO Visual Occlusion Spectacles (Translucent Technologies, Toronto, ON).

EMG activity. To measure EMG activity, participants had two self-adhesive Kendall Meditrace Ag/AgCl electrodes (Tyco, Mansfield, MA) positioned on their skin over the muscle belly of the left TA (Di Giulio, Maganaris, Baltzopoulos & Loram, 2009). Two electrodes were also positioned over the muscle belly of the left ECR (Cooke, Kavussanu, McIntyre, Boardley & Ring, 2011). Ground electrodes were attached to the head of the fibula and the olecranon process respectively. Prior to electrode application the surface of the skin was shaved of any hair and cleaned with an abrasive gel and alcohol wipe. EMG data was captured at a sampling rate of 1000 Hz using a CED 1902 dual system (Cambridge Electronic Design, Cambridge, UK).

Kinematic Changes. Movement kinematics of the putting motion were measured with a 3D motion analysis system (Optotrak 3D Investigator, Northern Digital Inc., Waterloo, ON) positioned to face the participant and collect movement data at 300Hz. Two infrared emitting diodes (IREDs) were fixed to the end of the putter blade and the distal shaft of the club. A third stationary IRED was positioned on the putting platform facing the Optotrak in line with the starting position of the putter.

Software. Custom software (E-prime, v 2.0 Psychology Software Tools Inc., Sharpsburg, PA) was used to synchronize the collection of kinematic and EMG data. Recording was triggered when the reed switch circuit opened at the moment the participant began their backswing. Once contact was made with the ball the microswitch circuit was opened and the spectacles were triggered to become occluded until the start of the subsequent trial.

Protocol

Participants were given five minutes before testing commenced to practice the putting task at both distances and accommodate to the experimental set-up. Prior to starting each block of trials, specific task instructions were provided and the participants were asked to focus on those instructions for the next 10 trials. A reminder about the current focus instructions was also provided halfway through each block of trials. Participants were asked to focus on one of three attentional focus conditions- external (focus on the target), internal movement (focus on your hands gripping the club and the position of your elbows) and internal stance (focus on distributing your weight evenly through both feet). For all trials participants were asked to start with the club face directly behind the ball. Initiation of the backswing signaled the Optotrak and

EMG to begin recording simultaneously for three seconds. Once contact was made with the ball, the spectacles immediately became occluded and vision remained obstructed until the putt was measured. Each participant completed 10 trials in each of the focus conditions at the two distances, for a total of 60 putts (Perkins-Ceccato et al., 2003). The order of each block of trials was randomized between participants to minimize order effects.

Data Analysis

Performance measures. Measurement of absolute error (AE) (cm) was completed by two lab assistants immediately following each trial. The AE demonstrates the difference between the performance of a trial and the actual goal. It provides information about the magnitude of error on a trial, however the source of the error is unknown and it provides a measure of error in only one dimension (Magill, 2006). The AE measurement was used to determine constant error (CE), which takes into account the direction of the error and provides an indication of directional bias (Magill, 2006). For CE in this experiment, overshooting the centre of the target was assigned a positive value, and undershooting the target was assigned a negative value. Taking the standard deviation of a series of CE scores also provided a variable error (VE) score, giving an indication of overall performance consistency regardless of accuracy relative to the target (Magill, 2006). A low VE score indicates a high degree of consistency across trials, and a high VE score indicates a low degree of consistency. Finally, radial error (RE) is the most comprehensive measurement for situations where accuracy is necessary in two dimensions, such as in golf putting. The length of the error in both the horizontal and vertical directions was calculated and squared separately. Both error values were then added and the square root was taken of the total (Magill, 2006). To allow RE to be calculated, it was necessary to determine the angle of the ball relative to the centre of the target in addition to measuring AE. A goniometer anchored to the midline of the distal end of the putting green was placed over the target and following the measurement of AE, the angle of the ball was recorded. This allowed both horizontal and vertical error to be determined using trigonometric calculations.

EMG activity. A sweep-based data acquisition and analysis system (Signal, v 5.09 Cambridge Electronic Design, Cambridge, UK) was used to analyze all EMG data. Raw EMG signals were rectified and smoothed using 2 pole Butterworth high pass (10 Hz) and low pass (100 Hz) filters. Root-mean-square (RMS) and standard deviation (SD) were then calculated for both muscles of interest for each trial. RMS is the preferred smoothing method used to analyze the amplitude of the raw EMG signal (De Luca, 2002). The interference pattern produced during muscle activity is random, due to the variability in the motor units that are available to be recruited. Therefore, the raw EMG burst can never be exactly reproduced by the muscle. During the RMS smoothing procedure, the non-reproducible part of the signal is minimized and an outline is provided for the mean trend of signal development (Konrad, 2005). This mean rectified value is proportional to the number of active motor units and their average firing rate, and reflects the mean power of the EMG signal produced by the muscle of interest.

Figure 2. Visual Representation of RMS Average

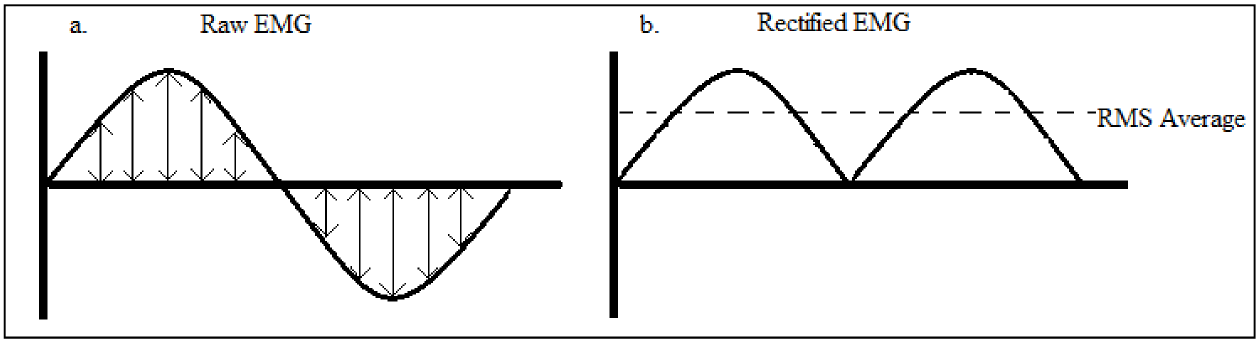

Figure 2. Schematic diagrams of a raw EMG signal (a) and a rectified EMG signal (b). In diagram (a) arrows represent individual data points used to calculate the average RMS as indicated in (b) with the dotted line. Note: this is a simplified representation of EMG and not actual EMG data.

Kinematic Measures. Kinematic data derived from the displacement of the putter in the frontal plane were analyzed using custom software (Matlab, v 2013b Mathworks, Natick, MA). Movement time (MT) (ms), time to reach peak acceleration (TTPA) (ms), time to reach peak velocity (TTPV) (ms), peak acceleration (PA) (m/s^2), peak velocity (PV) (m/s) and peak displacement (PD) (cm) were all calculated for the backswing and fore swing as two separate phases. Backswing was defined as the onset of the swing in the negative direction until the specific moment where the displacement value transitioned to moving in the positive direction (the start of fore swing). Fore swing was terminated at the end of the follow-through when the velocity of the putter fell below 10 m/s for a minimum of 40 frames.

Statistical Analyses

Statistical analyses were completed using SPSS Software (v 22 IBM Corporation, Armonk, NY). For all performance, EMG and kinematic measures, separate 2 group (novice golfers, expert golfers) x 2 distance (3 m, 5 m) x 3 focus of attention conditions (external, internal movement, internal stance) mixed model analysis of variance (ANOVA) designs were used with repeated measured on the last two factors. Planned comparisons were completed on non-significant interactions relevant to the experimental objective. Post-hoc analyses were performed on significant focus condition main effects involving more than two means and interactions as required using Tukey's Honestly Significant Difference (HSD). Statistical significance was defined by an alpha level of $p<0.05$.

Results

Accuracy

Constant error (CE). Analysis between both groups of participants revealed a statistically significant three-way interaction between participant group, distance to target and focus condition, $F(2,44)=3.463$, $p=0.040$. Tukey's HSD post-hoc comparisons of the three focus conditions revealed that when putting to the 5 m target, the novice participants had significantly higher CE scores when using the internal stance focus instructions ($M=26.109$ cm, $SD=36.982$ cm) compared to the internal movement focus instructions ($M= -2.900$ cm, $SD=45.516$ cm). Comparisons between the external focus instructions ($M=10.600$ cm, $SD=47.570$ cm) and the other two focus conditions were not statistically significant.

Figure 3. Constant Error Scores

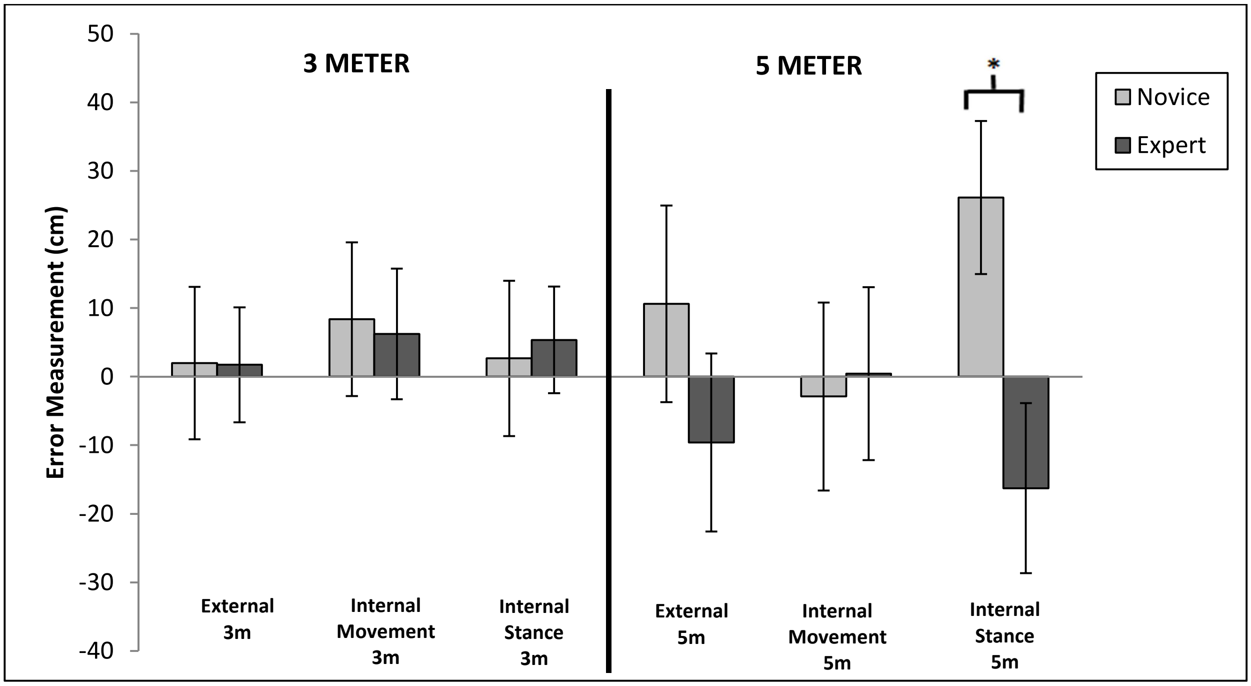

Figure 3. Mean constant error (cm) of putting trials as a function of distance to target and focus condition in both participant groups. Standard error of the mean is represented in the figure by the error bars attached to each column. Note: an asterisk denotes $p < 0.05$

Variable error (VE). A between groups analysis of the accuracy data produced a statistically significant main effect for distance to the target, $F(1,22)=52.638$, $p=0.000$. Participants had significantly higher VE scores when putting to the 5 m target (*M*= 43.908 cm, *SD*=19.311 cm) compared to when they were asked to putt to the 3 m target (*M*= 29.973 cm, *SD*=14.967 cm).

Radial error (RE). Analysis between both groups of participants revealed a statistically significant main effect for distance to the target, $F(1,22)=58.560$, $p=0.000$. Participants had significantly higher RE scores when putting to the 5 m target (*M*= 57.182 cm, *SD*=13.581 cm) compared to when they were asked to putt to the 3 m target (*M*= 37.545 cm, *SD*=16.148 cm).

EMG Activity

Tibialis Anterior

Root mean square (RMS). There were no statistically significant differences in the mean amplitude of the EMG signal found in either the novice golfer or skilled golfer groups or when data was analyzed across the two groups.

Mean Variability (SD). A main effect for focus condition, $F(2,24)=3.775$, $p=0.038$ was present within the skilled group. Post-hoc analysis using Tukey's HSD revealed significant differences between the three focus conditions in trials involving the 5 m target. Significantly less variability was produced in the EMG activity in TA when the internal stance focus instructions (M=0.022 mV, SD=0.020 mV) were used compared to the internal movement (M=0.026 mV, SD=0.022 mV) and the external focus instructions (M=0.028 mV, SD=0.025 mV).

Figure 4. Mean Variability in Lower Extremity

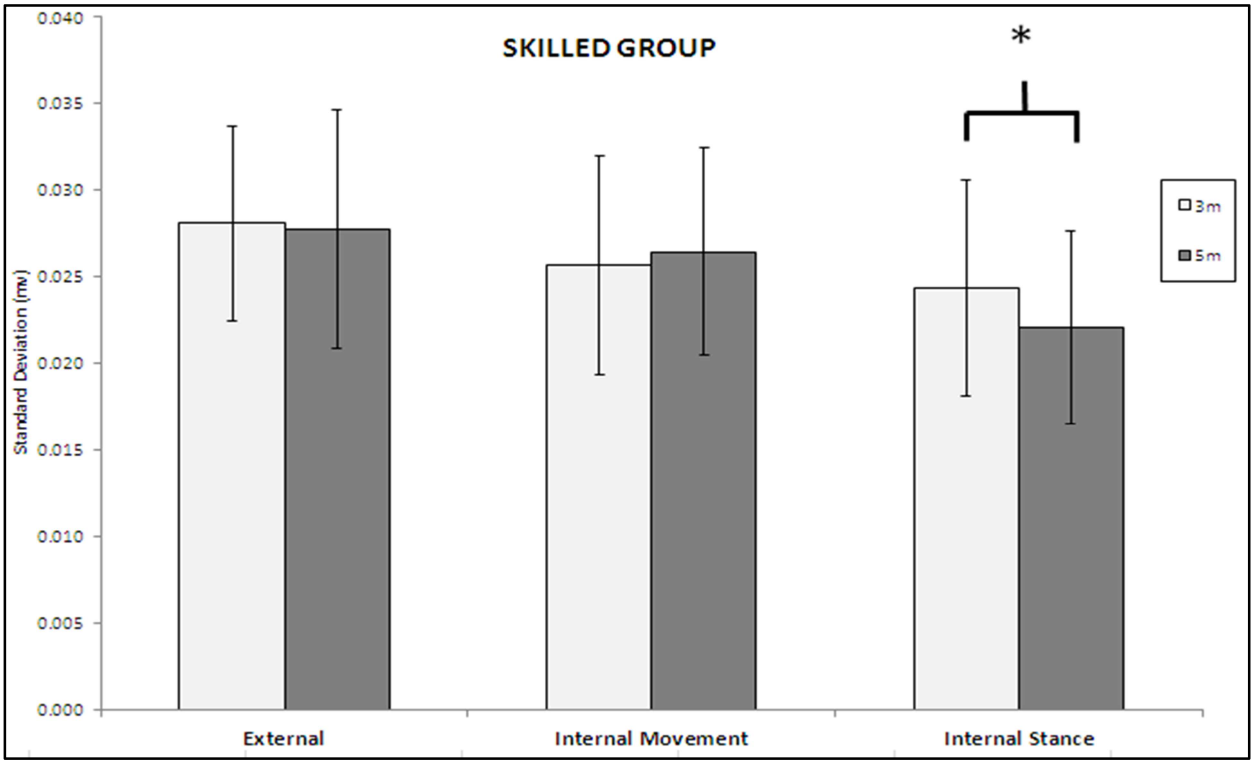

Figure 4. Mean variability (mV) of EMG activity in TA as a function of location of focus of attention instructions in skilled golfer participants. Standard error of the mean is represented in the figure by the error bars attached to each column. Note: an asterisk denotes $p < 0.05$

Extensor Carpi Radialis

Root mean square. A between participant group analysis revealed a main effect for distance to the target, $F(1,22)=9.532$, $p=0.005$. Participants had significantly more muscle activity in their upper limb when putting to the 5 m target (M= 0.203 mV, SD=0.127 mV) compared to the 3 m target (M= 0.188 mV, SD=0.116 mV)

Mean Variability (SD). A main effect for distance was found within the novice golfer group, $F(1,10)=9.615$, $p=0.011$. Novice participants putting to the 5 m distance had significantly more variability in the muscle activity of ECR (M= 0.0.055 mV, SD=0.028 mV) compared to activity at the 3 m distance (*M*= 0.048 mV, *SD*=0.024 mV). The skilled participant group also demonstrated a main effect for distance within their group, *F*(1,12)=8.141, *p*=0.015. Skilled golfers putting to the 5 m target had significantly more upper extremity muscular variability ((*M*= 0.046 mV, *SD*=0.027 mV) compared to when they were asked to putt to the 3 m distance (*M*= 0.042 mV, *SD*=0.025 mV).

Analysis between groups produced a three way interaction between participant group, focus condition and distance to the target, *F*(2,44)=3.399, *p*=0.042. Post-hoc comparisons of the three focus conditions using Tukey's HSD revealed statistically significant differences for novice participants when putting to the 5 m target. The internal movement focus instructions (*M*=0.062 mV, *SD*=0.035 mV) produced significantly more variability in ECR than when the internal stance focus instructions (*M*=0.048 mV, *SD*=0.021 mV) or the external focus instructions (*M*=0.053 mV, *SD*=0.028 mV) were used.

Figure 5. Mean Variability in Upper Extremity

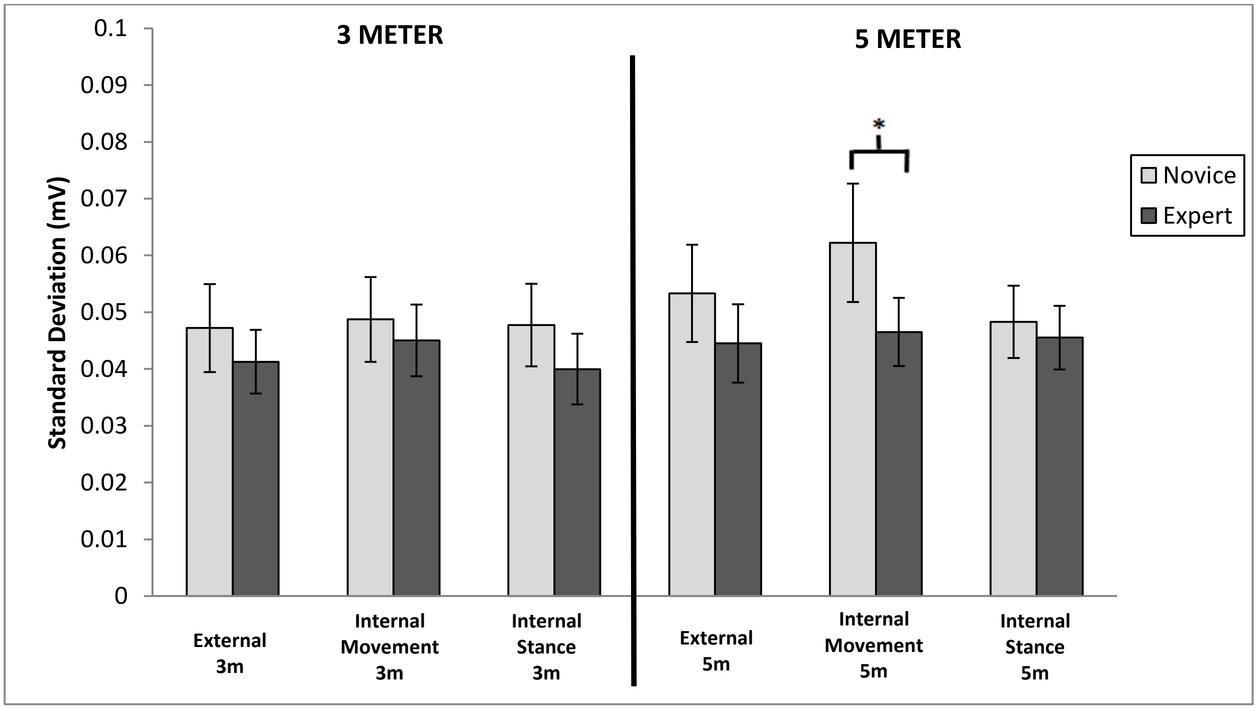

Figure 5. Mean variability (mV) of EMG activity in ECR as a function of distance to target and focus condition in both participant groups. Standard error of the mean is represented in the figure by the error bars attached to each column. Note: an asterisk denotes $p < 0.05$

Kinematic Changes

Club Backswing

Movement time (MT). Statistical analysis between the novice and skilled golfer groups revealed a main effect for distance to the target, $F(1,22)=32.716$, $p=0.000$ and a main effect for focus condition, $F(2,44)=6.884$, $p=0.003$. Post-hoc analysis using Tukey's HSD on the three focus conditions revealed significant differences in both of the participant groups. Novice golfers putting to the 3 m target demonstrated an increase in backswing MT when using the internal movement focus instructions (M=472.530 ms, SD=91.154 ms) compared to the internal stance focus instructions (*M*=437.530 ms, *SD*=115.983 ms). When the same group putted to the 5 m target a longer backswing MT also occurred when using the internal movement focus instructions (*M*=521.104 ms, *SD*=101.724 ms) compared to both the internal stance focus instructions (*M*=480.916 ms, *SD*=124.740 ms) and the external focus instructions (*M*=466.315 ms, *SD*=99.491 ms). Participants in the skilled golfer group had a statistically significant increase in backswing MT when putting to the 5 m target when using the internal movement focus instructions (*M*=516.781 ms, *SD*=169.406 ms) compared to the internal stance focus instructions (*M*=477.828 ms, *SD*=136.795 ms).

Figure 6. Backswing MT

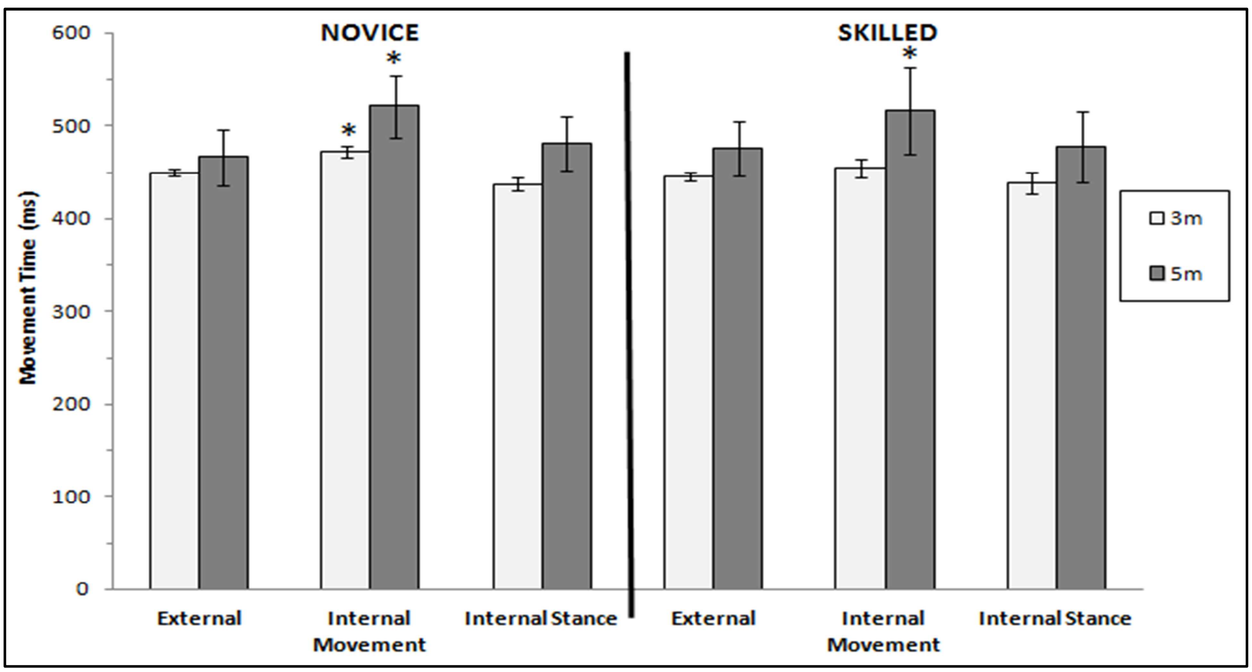

Figure 6. Mean movement time (ms) of backswing as a function of distance to target and focus condition in both participant groups. Standard error of the mean is represented in the figure by the error bars attached to each column. Note: an asterisk denotes $p < 0.05$

Time to Peak Acceleration (ttPA). There were no statistically significant differences in backswing ttPA found in either the novice golfer or skilled golfer groups or when data was analyzed across the two groups.

Time to Peak Velocity (ttPV). Analysis between both groups of participants produced a statistically significant main effect for distance to the target, $F(1,22)=33.023$, $p=0.000$ and a main effect for focus condition, $F(2,44)=5.530$, $p=0.007$. Post-hoc analysis of the three focus conditions using Tukey's HSD revealed that when novice participants putted to the 5 m distance using the internal movement focus instructions (M=222.750 ms, SD=79.508 ms) they demonstrated a significant increase in the backswing ttPV compared to the external focus instructions (M=205.101 ms, SD=62.701 ms).

Figure 7. Backswing ttPV

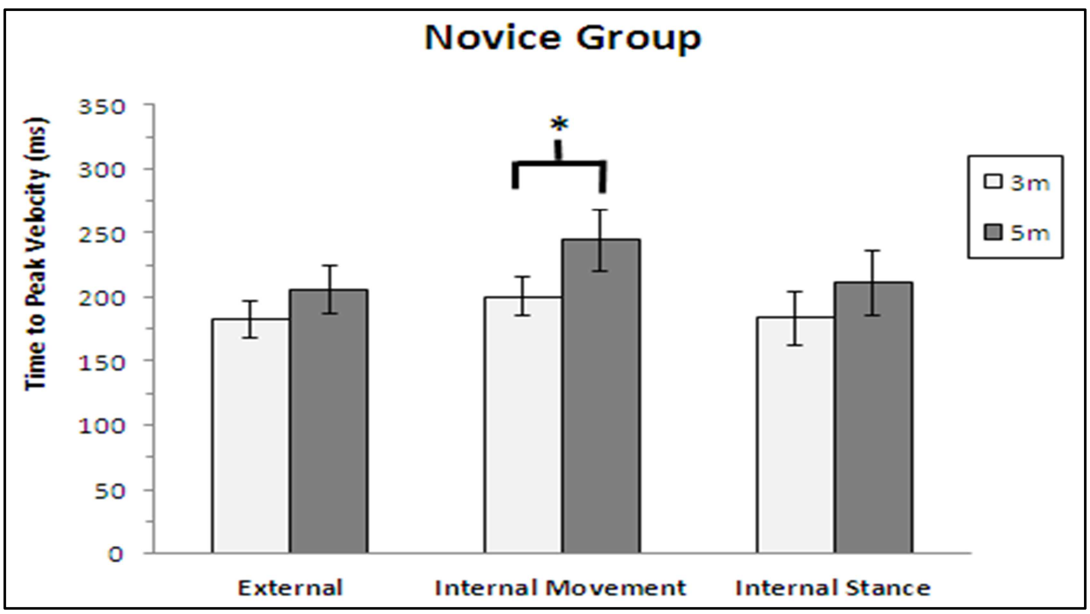

Figure 7. Mean ttPV (ms) of backswing as a function of distance to target and focus condition in novice golfer participants. Standard error of the mean is represented in the figure by the error bars attached to each column. Note: an asterisk denotes $p < 0.05$

Peak acceleration of club (PA). A main effect for distance to the target, $F(1,22)=34.263$, $p=0.000$ was present between both groups of participants. All participants demonstrated a statistically significant increase in backswing PA when putting to the 5 m distance ($M=-2594.981 mm/s^2$, $SD=996.809$ mm/s^2) compared to the 3 m distance ($M=-2096.981 mm/s^2$, $SD=728.964$ mm/s^2).

Peak velocity of club (PV). A main effect for distance to the target, $F(1,22)=136.574$, $p=0.000$ was present between both groups of participants. Participants putting the ball to the further distance of 5 m had a statistically significant increase in the PV of the club during their backswing (*M*=-547.144 mm/s, *SD*=132.434 mm/s) compared to the PV of the club at the 3 m distance (*M*=-431.127 mm/s, *SD*=95.818 mm/s).

Peak displacement of club (PD). There were no statistically significant differences in backswing PD found in either the novice golfer or skilled golfer groups or when data was analyzed across the two groups.

Club Fore Swing

Movement Time (MT). There were no statistically significant differences in fore swing MT found in either the novice golfer or skilled golfer groups or when data were analyzed across the two groups.

Time to Peak Acceleration (ttPA). Analysis across participant groups revealed a main effect for focus condition, $F(2,44)=6.074$, $p=0.005$. Post-hoc analysis using Tukey's HSD revealed significant differences between the effects of the three focus conditions. The internal movement focus instructions (*M*=365.600 ms, *SD*=115.041 ms) increased the fore swing ttPA significantly more than both the external focus instructions (*M*=327.987 ms, *SD*=51.540) and the internal stance focus instructions (*M*=325.550 ms, *SD*=48.917 ms) in the novice participants putting to the 3 m target.

Figure 8. Fore swing ttPA

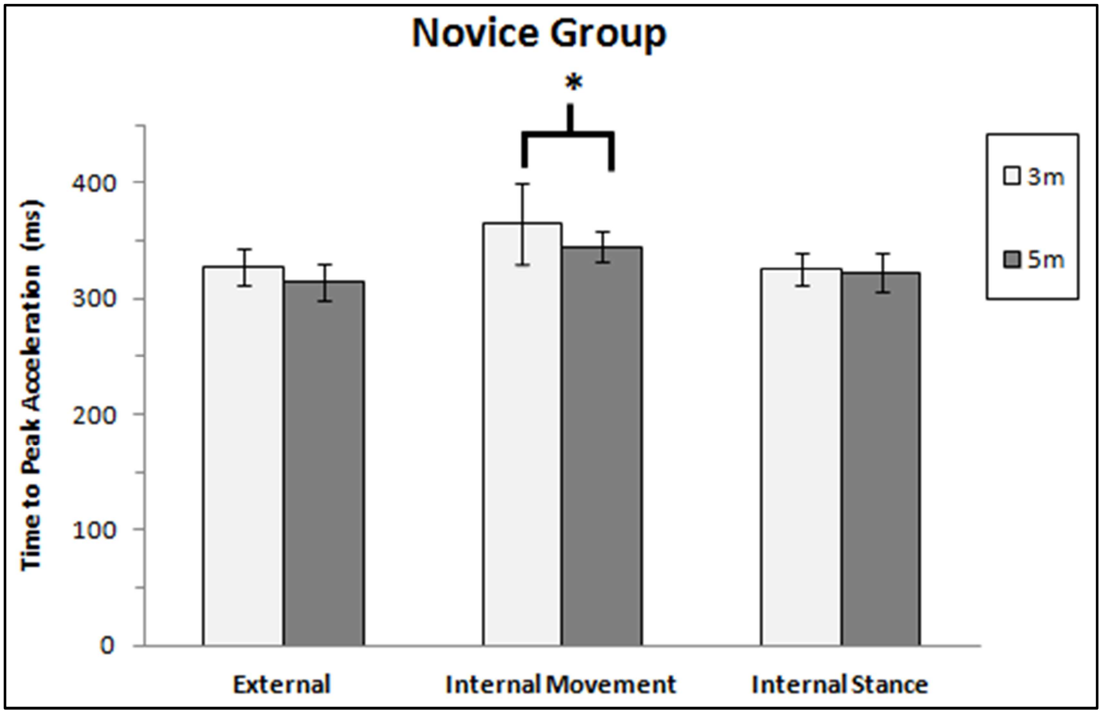

Figure 8. Mean ttPA (ms) of fore swing as a function of distance to target and focus condition in novice golfer participants. Standard error of the mean is represented in the figure by the error bars attached to each column. Note: an asterisk denotes $p < 0.05$

Time to peak velocity (ttPV). A between participant group analysis produced a main effect for focus condition, $F(2,44)=4.901$, $p=0.012$. Further post-hoc analysis revealed a statistically significant difference in ttPV when novice participants putted to the 5 m target. The internal movement focus condition (*M*=320.356 ms, *SD*=52.262 ms) caused an increase in the ttPV of the fore swing compared to the external focus condition (*M*=292.665 ms, *SD*=49.744 ms).

Figure 9. Fore swing ttPV

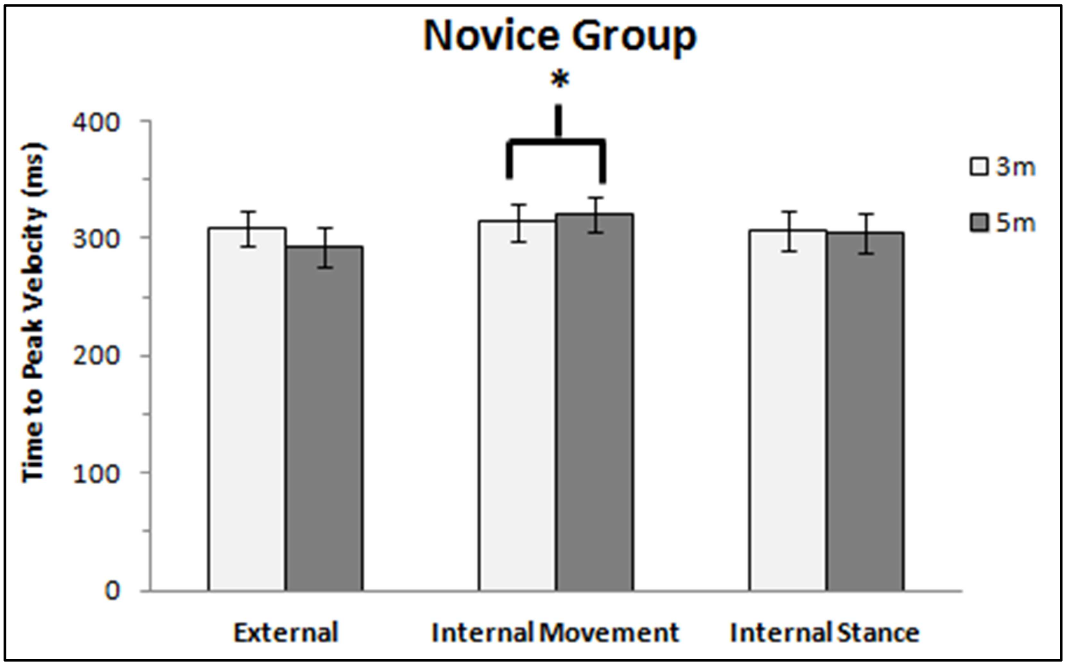

Figure 9. Mean ttPV (ms) of fore swing for 5 m target based on focus condition. Standard error of the mean is represented in the figure by the error bars attached to each column. Note: an asterisk denotes $p < 0.05$

Peak acceleration (PA). A main effect for distance, $F(1,22)=146.885$, $p=0.000$ was found between participant groups. Participants putting to the 5 m distance had a statistically significant increase in the PA of their fore swing (M= 37956.054 mm/s^2, SD=10065.905 mm/s^2) compared to when they were putting to the 3 m distance (M=28778.675 mm/s^2, SD=7855.040 mm/s^2).

Peak velocity (PV). A main effect for distance, $F(1,22)=136.574$, $p=0.000$ was found between participant groups. Participants putting to the 5 m target had a statistically significant increase in the PV of their fore swing (*M*=1561.151 mm/s, *SD*=95.409 mm/s) compared to the 3 m target (*M*=1166.940 mm/s, *SD*=92.564 mm/s).

Peak displacement (PD). A between group analysis revealed an interaction between distance to target and participant group, $F(1,22)=4.481$, $p=0.046$. Participants putting to the 5 m distance showed a significant increase in the peak displacement of the club in the fore swing (*M*=-38006.345 mm, *SD*=12106.253 mm) compared to the 3 m distance (*M*=-27466.973 mm, *SD*=9670.912 mm). However, post-hoc analysis using Tukey's HSD revealed no significant differences between any pairings of the means.

Discussion

The purpose of the present study was to examine the performance and underlying physiological effects of attentional focus in a golf putting task among skilled and novice golfers. Previous studies involving attentional focus have taken the approach of examining one dependent variable at a time, usually measuring a performance outcome (Wulf, 2013). A small number of studies have examined two dependent variables in an attempt to demonstrate why performance outcomes change when attentional focus is manipulated (Zachry et al., 2004, Wulf & Dufek, 2009). Lohse and colleagues (2010) took the unique approach of combining performance, neurophysiological and kinematic measures in an attempt to explain the underlying cause of performance changes that occur with alterations in attentional focus.

The current experiment followed the lead of Lohse et al. (2010) and used a triad of dependent measures to determine how accuracy, neurophysiological activity in select upper and lower body muscles and kinematic performance were impacted by the focus of task instructions. A novel aspect was the inclusion of two internal foci conditions, one relevant to task execution, and the other internal in nature but distal to the actual task. The two internal focus conditions were included to help determine whether the effects of attentional focus affect the whole body or whether they are localized to areas critical to task execution. All participants completed putting trials to two distances using an external focus of attention, an internal focus of attention based around the putting movement and a second internal focus based on their putting stance. Several key differences were noted across all measures between the two participant groups, highlighting both the performance effects and underlying mechanisms by which they were produced.

Participants in the novice group produced increased variability of muscular activity in the upper extremity (ECR) when the focus of attention was on the position of the hands and elbows (internal movement) as opposed to both the target (external) and weight distribution through the feet (internal stance). Previous studies examining physiological markers of attentional focus have found overall EMG activity in agonist and antagonist muscles to be reduced when using an external focus of attention (Vance et al., 2004; Marchant, Greig & Scott, 2009; Zachry et al., 2005; Lohse et al., 2010). ECR is noted as one of the muscles involved in the putting stroke (Cooke et al., 2011). Variability in muscle activity is a reflection of muscular output and thus the results of the current study support previous work. In our experiment, one of the key upper body muscles involved in task execution (ECR) was found to be less coordinated and less efficient when the novice participants performed the putting task. Although there were two internal focus conditions used in the experiment, the instructions which were anatomically proximal to the critical elements of skill execution had the most significant physiological effect on only the novice performers. Our results imply that internally focused task instructions which are proximal to the actual task have a more detrimental effect on movement efficiency for those without a prerequisite degree of automaticity. These findings are in line with the Challenge Point Framework (Guadagnoli & Lee, 2004). According to the Framework, performance of a motor task is a function of two variables, skill level and task difficulty. The nature by which those variables interact determines the optimal challenge point of a task and in turn explains performance differences due to skill level. An internal focus of attention which is normally detrimental to performance may be contingent on task experience and skill level. As the skill level of the performer increases, it is possible that the distance of the internal focus of attention required to produce significant physiological differences may also increase.

In the current study, the two sets of internally focused task instructions also produced differences in putting accuracy in the novice group of participants. Converging evidence from numerous studies (Wulf, 2013) states that an internal focus of attention has a negative effect on accuracy when it is the main goal of a task. The constrained action hypothesis is widely accepted as an explanation for these results, as focus on an individual's own body while executing a task may disrupt the normal processes controlling the movement. This disruption in turn yields a negative effect on performance across a wide range of tasks (Wulf, 2013). In the current experiment, focusing on weight distribution through the feet (internal stance) led the novice participants to perform far worse with regard to overshooting or undershooting the target compared to focusing on their hands and elbows (internal movement) at the 5 m distance. Although significant differences were found solely between the two internal focus conditions, performance outcome measures indicate no detriment to accuracy when an external focus of attention was used. These results are consistent with what is currently accepted in the research, as there is evidence that an internal focus of attention interfered with performance by increasing the constant error of the trials. Although the significant differences were found with the distal task instructions, for novice performers the location of the internal focus of attention may not be as critical when assessing accuracy. According to the current results, any focus that is on the performer's own body may be enough to disrupt the performance outcome of the task. These results refute previous findings by Perkins-Ceccato et al. (2003) who used similar golfer population groups but found that an internal focus of attention improved performance for the novice golfers. Although both skills are required in a standard game of golf, there are several key differences between golf putting and golf pitching. The differences may account for inconsistencies in the results between the two studies. For example, differences include the specific design features of the club, the motor patterns required to execute each skill, and the actual goals of the individual skills.

Consistent with the neurophysiological and performance effects that an internal focus of attention had on the novice golfers, several kinematic variables produced during the putting motion were also affected when an internal focus of attention was used. When novice participants focused on their hands and elbows (internal movement) during the putting motion, there were significant differences found in both the backswing and fore swing compared to when the focus was on the weight distribution of their feet (internal stance) or on the target (external). Backswing MT was increased at both distances, indicating that the internal focus instructions, which were directly related to the putting motion, had an effect on the mechanism of the task. For the novice golfers, the internal focus of attention caused them to slow down their backswing, indicating that more time was needed for online control of that portion of the movement. At the 5 m distance only, the ttPV of the backswing was also affected significantly compared to when the novice golfers focused internally on their stance. The 5 m distance finding indicates that when putting to a further target with a higher degree of difficulty, the novice golfers took more time in the online control of their movement before transitioning into the fore swing.

The fore swing of the novice golfers was also affected by the internal movement focus condition. When putting to both the 3 m and 5 m distances, ttPA was significantly longer compared to when the other two focus conditions were used. At the 5 m distance only, ttPV was also significantly longer compared to when the external focus condition was used. Online planning of a movement is indicated by the kinematic variables ttPV and ttPA. The longer it takes for peak velocity or peak acceleration to be reached, the more online planning that has occurred and the longer it takes for the individual to fully commit to the movement. An increased requirement for online planning seems reasonable among the novice participants, as ingrained motor patterns are not present and the putting movement cannot be completed unconsciously. Consequently, novices must make several online adjustments before finalizing task execution. In the current experiment the internal movement focus condition produced significant changes in the fore swing kinematics of novice golfers. The same focus condition also produced changes in the variability of muscle activity in the upper limb, indicating the underlying mechanisms behind the putting motion were affected by a focus that was proximal to critical elements of skill execution. Accuracy, however, was affected in the novice participants by the internal stance focus condition, which was distal to the putting motion. It is unclear why accuracy was not also affected by the proximal internal focus. However, it is evident that the external focus condition did not affect any of the three dependent measures in the novice golfers, which is consistent with the wide body of research supporting automaticity.

It should be noted that kinematic differences were only found in the novice golfer group, and the putting kinematics of the skilled golfers were largely unaffected by changes to attentional focus instructions. The only behavioural performance measure affected by the internal movement focus condition in the expert group was backswing MT to the 5 m distance. It is unclear why this one variable showed significant differences when the internal focus condition relevant to the putting movement was used. The skilled golfers were not adversely affected in their performance outcomes, so the increase in MT did not have an effect on their overall putting accuracy at the 5 m distance. An explanation may be attributed to a disruption in the automaticity that would normally accompany using an internal focus of attention directly connected to the golf putting movement. Skilled golfers, however, were able to overcome the change in backswing MT and retain normal kinematics throughout the putting motion regardless of the behavioural change in their backswing. The automaticity developed in the motor patterns of skilled golfers over time is evident as they performed with skill on a consistent basis through each block of trials.

A novice performer can be easily disrupted and performance outcomes are vulnerable when executing an unfamiliar task because motor patterns have not been established over time. In the current study, the novice participants were significantly affected when using an internal focus of attention, however the expert group maintained their level of accuracy even with changes to their attentional focus. Resilience to manipulations in task instruction are what allow skilled performers to execute a task consistently in a variety of conditions, while a novice is constantly looking for cues to assist them in completing a task. While the cues may initially improve their performance, inconsistencies will result over time as attentional focus cues are altered and the final outcomes may suffer.

While the current study found support for previous attentional focus research in the novice participant group, a unique result was found among the skilled golfer group that was not cohesive with current literature. The EMG activity in the lower limb (TA) in the skilled participant group produced decreased variability when the focus was on the weight distribution through the feet (internal stance) at the 5 m distance, compared to when the focus was on the target (external) or on the hands and elbows (internal movement). The finding as it stands is inconsistent with previous attentional focus literature, as the constrained action hypothesis clearly states that an internal focus of attention should act as a detriment to skill execution and performance. This is clearly not evident in the current experiment, as focusing on the lower limb (an internal focus) produced decreased variability of muscle activity in that region in the skilled participants. Perkins-Ceccato et al. (2003) used two groups of participants, experts and novices, in their golf chipping study and also found favourable results when using an internal focus of attention. However, it was the novice group who was able to improve performance by using an internal focus, and their neurophysiological status was unknown as it was not a variable tested. Another key difference in the present study was the attentional focus conditions presented to participants, as multiple internally focused task instructions were not included in the study by Perkins-Ceccato et al. (2003). In the present experiment, it would appear as though the expert group of participants subconsciously interpreted an anatomically distal aspect of the putting skill (weight distribution through the feet) as an external focus of attention rather than an internal focus. This interpretational shift in focus supports previous attentional focus evidence and the constrained action hypothesis, as an external focus of attention allows a muscle to work in a more efficient and coordinated manner.

The current evidence brings to light an aspect of attentional focus research which has not been previously explored in the published literature. The distance of an internal focus of attention from elements relevant to skill execution would appear in our case to play a role in changing the physiological outcomes associated with focus manipulation. Previous research has generally only utilized a direct comparison of one set of internal and external focus instructions, although a few have compared proximal and distal instructions that were both external in nature (Wulf, 2013). To date there are no published studies we are aware of comparing the effects of multiple internal foci of attention. In our experiment, the skilled golfers were able to subconsciously distinguish task relevance between the two internal focus conditions. Focusing on the position of the hands and elbows (internal movement) is a critical element required for a positive outcome while putting a golf ball. The hands and the elbows form a direct extension of the club and are therefore essential to task execution. Although maintaining a balanced upright posture is also required to complete the task, it is not the critical element associated with the putting motion and is considered anatomically distal. While expert participants completed the putting task using a focus of attention that was on qualities of their own stance, the result was reduced variability of activity in those muscles responsible for maintaining a standing posture. The anatomically distal task instructions acted in place of a more traditional external focus of attention and produced results similar to what was expected based on previous research.

Results from the current experiment also revealed several main effects for distance among the triad of dependent measures. Significant differences relating to distance were found between the participant groups in the variable and radial error scores and in several kinematic measures of the backswing and fore swing. Fitts' Law, a robust model that demonstrates the relationship between amplitude, movement time and accuracy, can be used to explain these results. Fitts' Law predicts that in rapid, aimed movements to a stationary target, there is a trade-off between speed and accuracy to ensure successful execution of a task (Fitts, 1954). In the case of the current experiment, the target was constant at a diameter of 10.8 cm but the amplitude of the task changed between 3 m and 5 m depending on the trial block. An index of difficulty was calculated for each distance (3 m = 4.8 bits; 5 m = 5.5 bits) in accordance with the paradigm to highlight the increase in difficulty between the two targets. The novice golfers demonstrated significant differences in the accuracy of their trials as well as in the execution of the actual putting movement when they were instructed to putt to the 5 m target regardless of focus condition. The MT, ttPV, PA and PV of the backswing and the PA and PV of the fore swing were all affected by the increased degree of difficulty, indicating that putting to the far target had an effect on task execution. The main effect for distance that occurred between groups involving the RMS of ECR cannot be explained through Fitts' Law, however it seems likely that novice golfers putting to a far target may grip the club tighter, perhaps to harness more power out of their stroke. This strategy would produce an increase in the muscle activity variability in the upper limb as the forearms are an extension of where the club is being gripped. A skilled golfer, however, has established automaticity, which allows more consistency in muscle activity associated with the putting movement regardless of the distance to the target.

In a recent review, Wulf (2013) discussed several methodological issues found in previous studies that presented results conflicting with the benefits of an external focus of attention. A small selection of the research has provided evidence to support the benefits of an internal focus of attention (Peh et al., 2011; Zentgraf & Munzert, 2009; Perkins-Ceccato et al., 2003) as well as null effects when using an external focus (Castaneda & Gray, 2007; de Bruin, Swanenburg, Betschon & Murer, 2009; Emanuel, Jarus & Bart, 2008; Poolton, Maxwell, Masters & Raab, 2006). Wulf (2013) identified several reasons that may have produced these inconsistent results, all of which were addressed in the current experiment.

The first recommendation was to avoid providing visual feedback in all experimental conditions. If visual feedback is provided in a task requiring accuracy, task instructions may not be the primary variable affecting the outcome. It is important to eliminate as much non-instructional feedback as possible in order to have the experimental focus conditions drive performance. The current experiment addressed this concern, as all participants wore visual occlusion goggles which prevented knowledge of results from ball contact until after accuracy was measured. The goggles were worn for each trial across all experimental conditions, thus eliminating a key piece of feedback and allowing the participants' focus of attention to have a greater effect on the outcome.

Wulf (2013) was also critical of a few previous studies which providing task instructions not relevant to task performance (Zentgraf & Munzert, 2009; Perkins-Ceccato et al., 2003). Task instructions must be specific enough for performers to immediately understand what they are being asked to focus on, otherwise the potential effects of that focus may be lost. For example, the golf chipping study involving both novice and expert golfers by Perkins-Ceccato et al. (2003) has been criticized for providing focus instructions referring to different aspects of the golf chipping task, and not directly referencing the performer's body in the internal focus condition. This led to a vague set of task instructions, which may have confounded each other by not specifically referring to task performance. The present experiment adhered to the currently accepted definitions of an internal and external focus of attention (Wulf et al., 1998). The external focus of attention condition asked participants to focus on the target, which relates to the environment they are performing the task in. The two internal focus conditions both related directly to the participant's own body movements when they were completing the putting task. All three sets of task instructions were relevant to the actual task that was performed by all participants.

The level of task difficulty has also been questioned in previous studies (Castaneda & Gray, 2007; Emanuel et al., 2008; Poolton et al., 2006, Experiment 2) which have produced results inconsistent with the current support for an external focus of attention. Participants in a baseball batting study (Castaneda & Gray, 2007) were asked to make judgements about their technique using an internal or external focus, creating a dual task situation. Their experimental design added extra difficulty to the task and may have confounded the final results. Studies by Emanuel et al. (2008) and Poolton et al. (2006) also placed a heavy informational load on participants during task execution. A large number of instructional conditions were presented to participants, which may have obscured the actual results of manipulating attentional focus. Our current experimental design presented task instructions in a manner which was easy for the participant to understand, regardless of skill level. Participants were asked to putt the ball as close as possible to the target, without any additional demands to create a dual task situation. Golf putting is a relatively simple task which places few extraneous demands on the participant beyond hitting a stationary ball with an implement to a target. The simplicity of the task was enhanced with the use of a highly controlled setting: an indoor putting green in a stable laboratory environment. The inclusion of two target distances ensured that an appropriate level of difficulty was achieved in each of the two participant groups and that differences could be observed between them.

Lastly, Wulf (2013) stated that it is essential to minimize confounding factors between focus conditions. Opposing task instructions should be comparable in the wording and informational content that is presented to the performer. A wide range of previous work by Wulf and colleagues (Wulf & Su, 2007; Wulf et al., 1998; Wulf & Dufek, 2009) exemplified this important detail. In some cases, however, the wording of task instructions may have led to contradictory results (Emanuel et al., 2008; Perkins-Ceccato et al., 2003; Zentgraf & Munzert, 2009). One of the main objectives of the current study was to compare two sets of internally focused task instructions at different locations within the body (hands/elbows and feet). The external focus condition (the target), however, referred to a different aspect of the task relative to the internally focused instructions. The intent of the design was to explore differences between locations of internally focused task instructions and use the external condition as a secondary comparison.

Limitations

A well-known limitation common to all attentional focus research is evidence that task instructions are being used as directed in each of the focus conditions. Task instructions may be presented to a participant, and the participant may state they understand, however what they actually focus on is unknown to the researcher. Focus of attention studies need to move towards the inclusion of technology which allows brain activity to be monitored while attentional focus is manipulated, such as with functional magnetic resonance imaging (fMRI). A recent study by Zentgraf, Lorey, Bischoff, Stark and Munzert (2009) was among the first to use fMRI while participants completed a key-press task under different focus conditions. Higher activation was found in the primary somatosensory and motor cortex when an external focus (keys) was used relative to an internal focus (fingers). However, more investigation is needed to explore if results can be generalized to other motor tasks which are not tactile in nature (Wulf, 2013).

Our study used two specific sets of participants for data collection, which may have led to sampling bias. Any potential participants who met the handicap requirement but held a putter left-handed were excluded from participation, due to the experimental set-up in the laboratory. Individuals who used a non-traditional grip on the putter were also excluded from participating. Although it was not a stated objective of this study, the expert and novice participant groups were not gender matched. There was only one female participant in the expert golfer group, and only three male participants in the novice golfer group. Finally, the specific task used the current experiment may make it difficult to generalize the findings across to other populations and motor tasks.

Conclusion

The current study assessed the effects of altering the focus of attention in a golf putting task using a triad of dependent measures. Skilled and novice golfers completed a putting task to two distances using an external focus of attention, an internal focus proximal to the critical elements of task execution and a second internal focus of attention distal to the putting movement. Performance accuracy, EMG activity in the upper extremity and putter kinematics were all negatively affected in the novice participants when the focus of attention was anatomically proximal to the putting movement. Behavioural aspects of the backswing in skilled participants were also adversely affected when the internal focus was on elements critical to skill execution. However, skilled participants possessed a high degree of automaticity with the putting movement and were able to preserve accuracy. The internally focused task instructions which were anatomically distal to the critical elements of the putting motion only caused the mean variability of EMG activity in the lower limb of skilled participants to decrease. The skilled golfers were able to subconsciously treat the distal internal focus of attention as an external focus and thus movement economy was improved. Our study addressed a gap in the current literature concerning the effects of multiple internally focused task instructions. The location of an internal focus of attention paired with the skill level of the performer was found to play a role in performance, neurophysiological and kinematic aspects of task execution. It is essential for future research to consider the wording of internally focused task instructions, as differences in their location relative to the critical elements of the task may affect outcomes.

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Appendix

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RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM

Title of Study: Focus of attention during skilled and unskilled golf putting.

Principal Investigator: Valerie Pelleck, RR318, Rehab Hospital, [redacted] Co-Investigator: Dr. Steven Passmore, RR317, Rehab Hospital, [redacted]

You are being asked to participate in a research study. Please take your time to review this consent form and discuss any questions you may have with the study staff. Please ask the study's investigator to explain any information that you do not clearly understand.

Purpose of Study

This research study is being conducted to evaluate golf putting performance when presented with different focus instructions. This information is being collected in a single session with both skilled and beginner golfers.

Study Procedures

Participant recruitment for this study is from various posters around the city of Winnipeg as well as through advertisement at local golf clubs and Golf Manitoba.

In this study, you will be tested in a single session performing several repetitions of a golf putting task from two distances.

If you chose to participate in this study, you will be asked to do the following:

- Visit with the Research Assistant.
- Wear a hat marked with an infrared emitting diode during the putting task (a small device that looks like a disc that collects information about head position and movement).
- Wear a pair of goggles that will not allow you to see where you putt the ball.

- Wear surface electrodes on your left forearm and left shin (about the size of a quarter) that will measure the electrical output of your muscles while you are performing the putting task.
- Take part in a practice session where you will putt the ball from various locations to get accustomed to the equipment that is attached to you.
- Putt a golf ball to one of the distances with one of four specific sets of instructions (10 putts to each for a total of 40 putts).
- Putt a golf ball to the other distance with one of four specific sets of instructions (10 putts to each for a total of 40 putts).

The visit will take approximately 60 minutes.

Risks and Discomforts

There are no risks involved in participating with this study. Should you become fatigued during any of the trials you may sit down and have a short break at any time.

Benefits

There are no direct health benefits from participation.

Costs

All of the activities which you will take part in as part of this study are provided at no cost to you.

Payment for Participation

For your participant in this study, you will not be receiving any reimbursement or payment.

Confidentiality

Information gathered in this research study may be published or presented in public forums; however, your name and other identifying information will not be used or revealed. Medical records that contain your identity will be treated as confidential in accordance with the Personal Health Information Act of Manitoba. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

The University of Manitoba Health Research Ethics Board may review records related to the study for quality assurance purposes.

Voluntary Participation/Withdrawal From the Study

Your decision to take part in this study is voluntary. You may refuse to participate or you may withdraw from the study at any time for any reason by communication in any form with the study's investigator. If the study staff feels that it is in your best interest to withdraw you from the study, they will remove you without your consent.

Medical Care for Injury Related to this Study

You are not waiving any of your legal rights by signing this consent form nor are you releasing the investigator(s) from their legal and professional responsibilities.

Questions

You are free to ask any questions that you may have about this study during your participation. Alternatively, please contact Valerie Pelleck at [redacted] should you have questions following your participation in the study.

For questions about your rights as a research participant, you may contact The University of Manitoba, Bannatyne Campus Research Ethics Board Office at [redacted].

Do not sign this consent form unless you have had a chance to ask any questions you might have, and have received satisfactory answers to all of those questions.

Statement of Consent

I have read this consent form and have had the opportunity to discuss this research study with the principle investigator, Valerie Pelleck. I have had my questions answered by them in a language I understand. The risks and benefits have been explained to me. I understand that I will be given a copy of this consent form after signing it. I understand that my participation in this study is voluntary and that I may choose to withdraw at any time. I freely agree to participate in this research study.

I understand that information regarding my personal identity will be kept confidential, but that confidentiality is not guaranteed. I authorize the inspection of any of my records that relate to this study by The University of Manitoba Research Ethics Board, for quality assurance purposes.

By signing this consent form, I have not waived any of the legal rights that I have as a participant in a research study.

I agree to be contacted for future follow-up in relation to this study:

Yes __ No __

Participant signature ____________________ Date: ________________

Participant printed name ________________________________

Relationship (if any) to study team members ______________________

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has knowingly given their consent

Person obtaining consent __________________ Date: _________________

Person obtaining consent printed name ___________________________________