Effects an Internal and External Focus of Attention on Learning Golf Skills

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Abstract

Previous research indicated that an external focus of attention is more advantageous than an internal focus in a wide variety of skill domains for both learning and performing motor skills. However, some of the research used to arrive at this conclusion relied on irrelevant internal cues, which could have biased their findings in favor of an external focus of attention. To investigate the validity of cue importance, thirty-three novices from a University of Minnesota Physical Education (PE) golf class volunteered to participate in a putting study (Study 1) that compared an internal focus of attention cue (body focus) to an external focus of attention cue (focus on the effect). The student group included 21 males and 12 females. In contrast to a similar previous study that employed an internal cue rarely used by golf teaching professionals, Study 1 used internal and external cues selected by a PGA teaching professional. Study 1 revealed that putting performance was better for the internal than external cue. Study 2 included 68 University of Minnesota students. This group was also composed of novices from a PE golf class who volunteered to learn a golf chipping task (m=45, f=23). These students were divided into four different attentional-cue groups: Internal-arms, Internal-wrists, External, and Control. The internal-wrists cue was the more commonly used by teaching professionals and theoretically more relevant than the internal-arms cue. The external group focused on the motion of the clubhead while the control group was taught as a normal golf class. After two (25 min) practice sessions a retention test indicated no difference between the groups. However, after four more practice sessions, the control group improved significantly more from pretest to final retention (3 weeks after pretest) than the internal-arms group and the external group. The internal-wrists group was not statistically different from the control group. This latent effect suggests that findings from short-term studies may not be effective in inferring optimal learning strategies.

Table of Contents

List of Table……………………………………..……………………………………...vii

List of Figures……………………………………………………………………………viii

Chapter 1: Introduction…………………………………………………………………1

Research Questions and Hypotheses……………………………………………………7

Purpose of the Study…………………………..……………………………………...8

Significance of the Study……………………………………………………………..8

Chapter 2: Review of the Literature…………………………………………………..…10

Introduction to Attentional Focus…..………………………………………….............10

Mechanisms (action-effect principle and constrained action hypothesis) 12

Measurement………………………………………………………………………...13

Balance Tasks…………………………………………………………………….14

Speed and Endurance Tasks……..……………………………………………………..17

Accuracy Tasks…..………………………………………………………………….19

Accuracy tasks in Golf………………………………………...………………….22

Attentional Focus and Expertise………..……………………………………………...25

Gap in Research: Cue Choice………………………………………………………….30

Gap in Research: Length of Practice…………………………………………………..34

Summary……………………………………………………………………………….37

Purpose of Study 1……………………………………………………………………..37

Purpose of Study 2……………………………………………………………………..37

Chapter 3: Methodology…………………………………………………….……….39

General Methodology……………………………………………………………….39

Study 1 Method: Putting Study……..…………………………………………………40

Participants and Groups…………………………………………………………..40

Procedures……………………………………………..………………………..41

Statistical Analysis……………………………………………………………….…43

Study 2 Method: Chipping Study……………………………………………...43

Participants and Groups…………………………………………………………..43

Procedures……………………………………………..………………………..44

Statistical Analysis………………………………………………………………..47

Chapter 4: Results and Discussion…………………………………………………49

Study 1 Results….…………………………………………………………………..49

Study 1 Discussion………………………………………………………………….50

Study 2 Results……………………………………………………………………...52

Study 2 Discussion………………………………………………………………….55

Chapter 5: Conclusions……………………………………………………………...57

Summary and Conclusions………………………………………………………….57

Limitations…………………………………………………………………………..59

Future Research……………………………………………………………………..61

References………………………………………………………………………………66

Appendix A……………………………………………………………………………...78

Appendix B……………………………………………………………………………...79

List of Tables

Table 1 : Scoring Grid for Study 2……………………………………………………………..................43
Table 2: Study 2 Mean Scores for Retention and Group Levels…………………………………....49
Table 3: Study 2 Two-way ANOVA for repeated measures on factor retention………......50
Table 4: Study 2 Results of the post hoc pairwise comparisons on group means....……....51

List of Figures

Figure 1: Illustration of Professional Coaches and Players with Bending Arms….......32
Figure 2: Study 2: Diagram of Chipping Task……………….……………………………….....43
Figure 3: Study 1: Mean Number of Putts Made……………………………………………….47
Figure 4: Study 2: Mean Scores on Chipping Task …..………………….....……….....…….....50
Figure 5: Study 2: Mean Scores of Retention 1 and 2..………………….……………………51

Chapter 1: Introduction

Golf's most famous swing tip belonged to Ben Hogan. Hogan discovered a secret wrist movement midway through his career that changed the course of his golfing life and the direction of golf instruction for decades to come. From that point forward, Hogan was perhaps the most accurate ball-striker the game has ever seen. Hogan's secret was as simple as it was profound. Hogan realized that by cupping his left wrist at the top of his backswing he could open the clubface and not fear a hook (a golf shot that curved hard to the left). The cue allowed Hogan to play a repeatable shot for the rest of his golf career with great success. What's notable about Hogan's secret is that it contradicts a large body of research which identifies external cues as generally superior (Wulf, 2013). Yet, Hogan's experiences are not unique, which is why a deeper investigation into attentional focus and expertise is necessary.

Expertise in the area of golf, like other endeavors, requires a substantial amount of deliberate practice (Ericsson, 2008). Golf skills, in particular, can be challenging to learn due to the precise coordination of body and club movements required and the relatively counter-intuitive nature of ball flight physics. In addition, a golfer must master the coordination of hitting a golf ball relatively consistently with up to 14 different golf clubs from a nearly endless variety of course conditions, lies, weather conditions, and course design challenges.

Fortunately, unlike in other sports, golfers are provided ample time between golf shots to prepare. Unlike most ball sports, golf is not reactive. During a 4.5 hour round of golf, the average player hits a shot about every 3 minutes, with the typical pre-shot routine of a golfer on the course taking 15-25 seconds. During this time, pre-shot as well as between shots, a golfer must choose a strategy to maximize their score on a given hole. The golfer chooses where to aim, what club to hit, what shape to give the shot (curve either left or right), what trajectory (height) to hit a shot, how hard to swing, how the ball will come out of the lie, how the ball will react in the wind, and how much it will roll when it hits the ground. In addition, the golfer has the option of focusing his/her attention internally or externally. An internal cue narrows the golfer's focus to what their body is doing, while an external cue narrows the golfer's focus on what effect a movement is having on the ball, the club, or some other external object or the environment. The complexity of each shot coupled with the time allowed between shots make golf an ideal sport for understanding the role of attentional focus in learning and performance since the golfer navigates between both internal and external cue options in a constantly changing environment.

Tiger Woods' most iconic shot gives us a clue about what the best golfer of all-time focuses on. With the 2005 Masters on the line, Tiger faced a tricky downhill pitch from a bad lie in the short rough. His caddy Steve Williams described the situation:

> There's more to that Tiger hole-out than you probably know. After Tiger inspected the green and was walking back to his ball, he pointed out an old ball mark on the green. It was the size of a dime, almost fully healed, practically invisible. He said, 'You think if I hit that spot, it'll take the slope without going into the bunker?' ... I told him I liked that play. He then hit that old ball mark

> exactly, from 20 feet away from a tough lie. That the ball went in the hole was sort of a miracle, but hitting the old ball mark on the fly was one of the most amazing things I've ever seen (Gaines, 2019).

Williams' comments indicate that during that moment Tiger's focus was on a specific external target, yet Tiger has also talked extensively about focusing on his hands when hitting a specific shot. In his 12-part video series *My Game:* Tiger Woods says:

> "Controlling trajectory and controlling shots, a lot of that is my hands. . . . To me, it's about making the little adjustments right before impact to sense where the club is because at the end of the day the only connection we have to the golf club in our hands" (Woods, 2019).

Based on this testimonial evidence it would seem that one of golf's greatest players focuses both internally and externally at certain times. Tiger's attentional focus habits mirror that of the mixed advice provided by a typical Golf Digest publication which relies on both internal cues (60%) and external cues (40%) in its "tips" to readers (Tarde, 2020).

Anecdotally, great golf swings are typically built with a combination of external and internal cues over long periods of training. Golf's long list of internally focused champions (Nick Faldo, Nick Price, Tiger Woods, Bernhard Langer) have changed their swings several times during long and successful careers, with a significant emphasis placed on internal cues (Faldo, 2012; Price, 2009; Woods, 2001; Langer, 2003, Hardy & Andrisani, 2007). Yet, when performance is most critical, as it is in golf's most important tournaments, an external focus seems to be recommended by sports psychologists (Rotella, 2001) as well as its greatest coaches (Pennick, 1992) and champions (Woods, 2001; Faldo, 2012).

In contradiction to expert anecdotes indicating a mixed-use of external and internal cues, empirical evidence in the specific area of attentional focus research appears to mostly support external cues. In a 2013 review of attentional focus, Wulf (2013) states:

> The enhancements in motor performance and learning through the adoption of an external relative to an internal focus of attention are now well established. The breadth of this effect is reflected in its generalizability to different skills, levels of expertise, and populations, as well as its impact on both the effectiveness and efficiency of performance (p. 99).

Golf, of course, is just one of several activities used in research on attentional focus. Other areas of study include aspects of coordination, strength and endurance, and ball sports. Of all the areas of study, balance is the most frequently examined while golf is the second most common domain of investigation. The literature examines movement efficiency and movement effectiveness (an outcome measure). Like other areas of research on attentional focus, a majority of golf-related research on attentional focus indicates that external cues facilitate the improvement of movement form and effectiveness (Wulf, Lauterbach, Toole., 1999; Wulf, McNevin, Shea, 2001; Wulf & Su, 2007; Bell & Hardy, 2009; Christina & Alpenfels, 2014; An, Wulf, Kim, 2013; Granados, 2010; Perkins-Ceccato, Passmore, & Lee, 2013; Poolton, Maxwell, & Masters, 2006).

However, these studies, like a majority of the literature on attentional focus, rely on a very limited amount of practice on which to base conclusions. Extending these conclusions to golfers and athletes who spend months to years perfecting internal or external cues may lead to a different outcome. Perhaps the best example of this is Ben Hogan, golf's most esteemed technician (Hogan, 1985). To a beginner, Hogan's internal cue may seem very difficult to master, yet Hogan's mastery and skill with controlling the clubface led to winning multiple major tournaments -- the result of years and years of "grooving" the internal cue (Hogan, 1985).

Ben Hogan's path towards expertise is symbolic of the typical expert experience. Ericsson and Lehmann (1996) detailed the long road to expertise as a 10+ year journey built on the concept of deliberate practice. During this deliberate practice, experts must learn to alternate between different levels of skill development to continually advance their skills. Other experts emphasize the need to refine body awareness (internal awareness) and break skills into chunks for a reinvestment of technique (Beilock & Gray, 2007). Unfortunately, longitudinal causal research of this kind is difficult since it is difficult to monitor practice over a long period with a large number of participants. Yet, without a record of long-duration studies comparing internal and external cues for training we are left with conclusions that seem misaligned with anecdotal evidence.

Wulf's (2013) assertion that external cues are superior for performance and learning in virtually every situation may be poorly supported if more long-term studies with greater amounts of practice are added to the literature. While the performance benefits of an external focus in competitions seem fairly well supported both empirically and anecdotally, Shusterman (2008) and others (Beilock & Gray, 2007; Collins, Carson, Toner, 2016) have indicated that a more nuanced view should be considered when it comes to long term learning, with the likelihood that internal cues, or at the least internal awareness, can serve as a key function to expert training in certain situations.

Another area of potential weakness in the existing body of literature lies in the cue researchers choose to provide to participants. Generally, the criteria chosen for comparing internal and external cues is that the cues have comparable information with typically only a negligible difference between the loci of the focus (Wulf et al., 2001). Based on the broad choice of cues by researchers in the field it is not entirely clear if "comparable" relates to the wording used (i.e. swinging motion or putter or arms) or movement pattern elicited. Some studies seek to draw conclusions based on the outcome of the task alone while others support the conclusion with additional kinematic or movement data (Wulf, 2013). Yet, similar word choices might elicit very different movement patterns and outcomes, which begs the question, are the cues relevant. A relevant cue should be biomechanically correct and prescribed by professionals in the field of study – an indication of its general effectiveness. Based on this simple rubric we find that several key studies fall short (Wulf et al., 1999, Wulf & Su, 2007; Granados, 2010; An et al., 2013; Beilock, Bertendal, McCoy, & Carr, 2004).

In particular, Wulf et al's, (1999, 2007) internal cue asking participants to "keep the left arm straight in the backswing, both arms straight at impact, and the right arm straight and the left arm bent in the follow-through" is wordy and confusing, and arguably biomechanically incorrect. In spite of the limitations (p. 122, 1999), Wulf et al.'s, (1999, 2007) golf studies are some of the most widely cited in the literature.

Research Questions and Hypotheses

To address the research gap between anecdotal evidence and empirical evidence two research questions guided this study.

RQ1: Does the relevancy of attentional focus cues that are used to facilitate golf skill learning in acquisition influence the degree of that facilitation?

H_1: A more relevant attentional cue will facilitate golf skill learning more than a less relevant one regardless of whether the cue is internal or external.

RQ2: Are relevant attentional cues for golf skill learning a function of the amount of practice?

H_2: The facilitating effect of a relevant internal cue on golf skill learning will yield appreciably more than a relevant external cue with a greater amount of practice.

Study 1 was conducted to test H_1 and Study 2 tested both H_1 and H_2. A full description of both studies are described in Chapter 3, and the reporting of the results and discussion, and the conclusions, are presented in Chapters 4 and 5.

Purpose of the Study

Study 1 tested **H_1** by comparing a more relevant internal cue (motion of the wrists) to a less external cue (pendulum motion of the putter). The purpose of Study 1 was to identify the impact of cue relevancy in a simple putting experiment.

Study 1 and Study 2 also addressed the discrepancy between the attentional focus findings in the research literature (indicating a near-exclusive advantage an external focus), (Wulf, 2013) and many real-world training regimens employed by players and teacher/coaches that use internal cues (Bernier, Trottier, Thienot, & Fournier, 2015; Carson, Collins, & MacNamara, 2013; MacPherson, Collins, & Morriss, 2008; Nyberg, 2015; Orlick & Partington, 1988; Robazza & Bortoli, 1998). This was investigated over a greater length of practice (8 practice sessions in total) than a majority of previous literature, a test of **H_2**.

Significance of the Study

If Wulf's (2013) review of the attentional focus literature is correct, then much of the anecdotal evidence we have seen involving the use of internal cues by top golfers and athletes generally is misguided. Coaches, athletes, and sport's governing bodies should seek to quickly transition toward a more external focus of training as indicated by Wulf (2013). Conversely, it is possible that some of the attentional cue research findings are not generalizable to or do not reflect real-world situations because of earlier study limitations involving the amount of practice and relevance of the cues used. Specifically, the amount of practice provided in previous studies (between pretest and retention test) may not have been enough to generalize the results or reflect how attentional cues actually operate in real-world golf situations. And, this is further complicated by the fact that the various attentional cues that were arbitrarily selected for study may not have been similar or approximately equivalent in terms of their relevance for learning and performing. For instance, an attentional cue (internal or external) that (a) is preferred by authorities/experts because it makes more logical sense to use, and (b) to which students can more easily understand and relate might have been more beneficial for learning and performance than a cue that was not. The review of research literature presented in the next chapter explores the gap between the studies on attentional focus and the real world examples of learning through attentional focus.

Chapter 2: Review of the Literature

Introduction to Attentional Focus

Motor learning is defined as a relatively permanent change in the capability to respond or perform due to practice or a novel experience. It involves the speed, smoothness, and accuracy of responses to tasks or stimuli (Adams, 1971). An important distinction is made between learning and performance because the temporary changes apparent during practice are not considered learning. Rather, learning is typically inferred after a period of practice through a retention or transfer test, indicating a relatively permanent change (Schmidt, 1988).

The stages of skill acquisition have been well defined for decades. Fitts and Posner (1967) identified three basic stages of learning motor skills. The first and most basic level of skill learning is the cognitive stage, in which a beginner embarks on the task of learning a new motor skill through rough mental representations. The cognitive stage is slow and error-filled. Movements are disjointed, inconsistent, and responses to perturbations in the environment are very often poorly selected and ineffective. Learners in the cognitive stage often find themselves thinking about how their bodies must move in order to accomplish the task at hand. As practice time continues, learners move into the associative stage, in which they are able to control some portions of movements unconsciously. Movements become more refined and accurate and the speed of processing and reacting to contextual differences in the environment allows for a more varied practice environment. During the final stage of motor skill development, performers attain a level of automaticity that results in fast and precise movement patterns without significant conscious control. Performers in the autonomous stage are able to quickly and efficiently react to novel situations. Their focus tends to be on external stimuli as opposed to the internal body-related stimuli (Fitts and Posner, 1967). Fitts and Posner's stages of learning are critical to athletes and coaches because the mechanisms and stages of motor learning provide the roadmap to expertise. It is presumed a faster track towards automaticity will lead to higher levels of performance (Fitts and Posner, 1967).

The literature indicates that one's focus of attention, or allocation of mental resources to a particular cue, stimuli, or state, can directly impact learning (Wulf, 2013). Nideffer's (1976) early work in the area of attentional focus differentiated between direction (internal and external) and width (broad or narrow) of attentional focus. Stevinson and Biddle (1998) also proposed two dimensions, although they divided attentional foci along the direction (internal and external) and task-relevance (association or dissociation). Contemporary concepts of internal and external focus became more widespread as Wulf (see 2013 review) established an extensive line of research with consistent terms.

Wulf (2013) and a majority of the sports-related attentional focus work highlighted in this literature review focused predominantly one dimension (internal and external cues). The nuances of attentional focus have been studied in many different areas of sport (Wulf, 2013). In general, the conclusions indicate that as performers learn fastest when they focus externally (Wulf, 2013). In fact, Wulf (2013) concludes that given the extensive literature pointing towards an advantage for an external focus it appears that in virtually all tasks, all environments, and with all populations, we should see an advantage for an external focus of attention for both learning and performance. Wulf's (2013) review includes 80+ studies that indicate an external focus improves areas such as: movement effectiveness (e.g., better balance, higher accuracy), movement efficiency (e.g., reduced muscular activity, greater speed, higher peak force, and longer endurance), better movement form, and more automatic and fluid movements. There is also some support to a distal advantage to an external focus, with a focus on a more distal external target generally producing a more robust result than a more proximal external target (Bell & Hardy, 2009; Banks, 2012; McKay & Wulf, 2012; McNevin et al., 2003; Porter, Anton, & Wu, 2012).

Mechanisms (Action-Effect Principle and Constrained Action Hypothesis)

Academics have identified the Action-Effect Principle (Prinz, 1997) and the Constrained Action Hypothesis (Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001) as explanations for the superior results from an external focus. The theories have slightly different explanations but similar implications.

The action-effect principle asserts that participants perform best when they focus on the outcome (effect) rather than the specific movements that lead to the outcome (Wulf, Hob & Prinz, 1998). This leads to unconscious movement patterns that control the degrees of freedom through a more natural process (Wulf, Hob & Prinz, 1998). This enhanced control contributes to faster movement adjustments and improved performance and learning. Conversely, focusing attention on the body leads to cognitive processes that disrupt the natural automatic control processes present with an external focus. This occurs because the performer must pay attention to the outcome or effect of the movement, as well as the body movement required to produce that outcome, not unlike a dual-task (Palsher, 1994).

The Constrained Action Hypothesis (CAH) proposes that when performers focus on the body movement (internal cue), such a focus tends to degrade performance as a result of muscle co-contractions and a heavier load on processing systems (Wulf et al., 2001; Wulf, Shea, & Park, 2001). The significance of the CAH and the action-effect principle is that practitioners should recommend an external focus of attention instead of an internal focus of attention whenever possible.

Measurement

The effectiveness of an external or internal attentional focus can be measured by the outcome of the study (Wulf, 2013). However, researchers can also measure the underlying physiological processes that govern that outcome. In general, an automatic process requires less conscious control, which indicates a more efficient response (Abernethy & Abernathy, 1988). Commonly used physiological measures designed to measure efficiency include muscular activity (EMG), oxygen consumption, and heart rate. Another measure of a more automated motor process is movement fluency, which is defined as the smoothness of acceleration of moving limbs. Probe reaction times have also been used with the assumption that a more complex task will require more attentional focus and poorer performance on a probe reaction time test.

A discussion of common domains of attentional focus studies follows. Although tasks and measures of the underlying processes vary between domains, a trend toward more significant support for an external focus is apparent in both the performance on tasks as well as the physiological markers indicating a more efficient process (Wulf, 2013).

Balance Tasks

Postural balance tasks have shown remarkably similar results with an advantage towards an external focus. In a notable balance task experiment, Wulf, Höb, and Prinz (1998) divided 33 participants into internal, external, and control groups in a slalom-type ski simulator task. The internal group was asked to think about placing force on the outer foot while the external group was asked to think about placing force on the outer wheels. The control group was not provided any additional instructions beyond how to operate the ski simulator. All the participants practiced the task on 2 consecutive days and performed a retention test on the third day. The results indicated that the external group improved more than the internal and control groups, with the internal group performing as well as the control group. A second task, which involved a stabilometer instead of a ski simulator produced the same findings. Others have had similar balance findings using either stabilometers or ski-simulator tasks (Chiviacowsky, Wulf & Wally, 2010; Jackson & Holmes, 2011; McNevin, Shea & Wulf, 2003; Shea & Wulf, 1999; Wulf & McNevin, 2003; Wulf, McNevin, & Shea, 2001; Wulf, et al., 2003). Wulf, McNevin, & Shea (2001) have also shown that the underlying processes (automaticity), have contributed to a more efficient physiological response as indicated by lower probe reaction times for performer's utilizing internal foci as opposed to external foci.

Using a rubber disc instead of a stabilometer or ski simulator, Wulf, Mercer, McNevin, and Guadagnoli (2004) examined the influence that attentional focus on a postural or supra postural task had on the performance of each task. Thirty-two participants stood on an inflated rubber disk and held a pole horizontally. The participants were instructed to focus on the disk (external, postural), the pole (external, suprapostural), the feet (internal, postural), or the hands (internal, suprapostural). Compared with the internal foci, external foci on either task resulted in similar and reduced postural sway. Response frequencies and magnitude of frequency were also increased with an external focus.

A similar balance study investigating attentional focus also used a rubber disc but the participants were diagnosed with Parkinson's Disease. Wulf, Landers, Lewthwaite, and Tollner (2009) chose 14 patients with Parkinson's disease ages 52-80. The researchers brought an inflated rubber disc with a diameter of 33.02 centimeters to each participant's house. Participants were instructed to look straight ahead while balancing on the disc. A repeated-measure, within-subject design was used to assess differences between the conditions. Each participant performed four 15-second trials under three different conditions. In the control condition participants were instructed to "stand still". In the internal condition participants were asked to focus on "minimizing the movements of the feet". In the external condition, participants were asked to minimize the movements of the disc. The order of the trials was counterbalanced across participants so as to control for possible order and carryover effects. The results indicated that the external group had lower postural sway relative to both the internal and control groups.

Wulf, Tollner, & Shea (2007) had a similar finding using healthy students who performed a balance test under external, internal, and control conditions. In an attempt to investigate the potential differences between tasks of varying difficulty the students were asked to stand on solid and foam surfaces directing their attention either externally (equal pressure into force plates) or internally (equal pressure on feet). The results indicated that under less difficult conditions (solid surface) no difference was found between an internal and external focus of attention. However, as the task difficulty increased (foam surface) the external cue became more effective, indicating that a certain degree of stability may be a precondition for the attentional focus effects to occur.

Similar findings have been found using the Balance Master and Biodex Stability systems (Landers, Wulf, Wallmann, & Guadagnoli, 2005; Laufer, Rotem-Lehrer, Ronen, Khayutin, & Rozenberg, 2007; Thorn, 2006). Others have sought to use a Pedalo, which is a balance board on wheels consisting of two connected plates at different heights. Using a Pedalo, Totsika & Wulf (2003) again found that focusing on the external cue of moving the board, was more effective than thoughts related to moving the feet forward. Whenever control conditions were included (Landers et al, 2005; Wulf et al, 1998 Experiment 1; Wulf et al., 2003 experiment 2; Wulf et al. 2009) it was found that the control conditions yielded similar performances as the internal focus instructions.

Speed and endurance tasks

Merchant, Greig, Bullough, and Hitchen (2011) showed the influence of differential attentional foci on muscular endurance in trained individuals doing exercise routines. The researchers had participants perform bench press (on a Smith Machine), free bench press, and free squat with weights approximately 75% of each participant's maximum. An external focus of attention led to a greater number of repetitions than the internal cue, as well as the control group in most cases. Lohse and Sherwood (2011) also found that participants were able to hold their posture better in a wall sit task when they focused on keeping imaginary lines between their hips in knees horizontal (an external focus), as opposed to thinking about the horizontal position of their thighs (an internal focus).

In a 10-minute running task Schucker, Hagemann, Strauss, and Volker (2009) found that runners focusing on a virtual environment (external focus) reduced their oxygen consumption as compared to focus on their breathing (internal focus) or running movement (internal focus). The authors indicated that the reduced oxygen consumption indicated a more economical or efficient movement pattern.

An external focus of attention has also been shown to increase swim speed. Using a sample of intermediate crawl students, Freudenheim et al., (2010) found that participants achieved significantly shorter times when they focused on pushing water back (external focus) rather than pushing their hands back (internal focus) or on no instructions at all (control). Stoate and Wulf (2011) had similar findings with expert swimmers, except that the external focus with expert swimmers provided no additional benefit over the control condition, which the author attributed to the fact that the expert's movements were already highly automated. The authors also found that "normal" focus (i.e., control condition) of swimmers differed, with faster swimmers reporting more focus on overall outcomes (e.g., speed, tempo, going fast, swimming hard) as opposed to slower swimmers who favored more internal focus cues (e.g., hip rotation, spinning arms, high elbow). This finding draws similarities to a study by Jackson, Ashford, and Nosworthy (2006, Experiment 2), in which soccer players who focused on technique (internal focus) performed more slowly than soccer players who focused on a set goal related to the strategy, such as the position of the ball in relation to the cones (external focus).

In longer-duration tasks requiring maximal or sub-maximal force production over an extended period of time, an external focus of attention allows performers to apply more force and/or exert that force over a longer period of time. For example, Porter, Nolan, Ostrowski, and Wulf (2010) found that an external focus shortened the time needed to complete an "L" run, which is an agility task.

In a one-leg extension-flexion task, Kal, van der Kamp, & Houdijik (2013) showed that performers showed superior motor performance when under an external focus as compared to an internal focus. The researchers also measured dual-task costs through EMG activity. The EMG activity indicated that the internal cue acted as a dual-task, significantly increasing the costs of working memory.

In the domain of music performance, Duke, Cash, and Allen (2011) asked music majors to perform a keyboard passage consisting of 13 alternating sixteenth notes (A and

F) as quickly and evenly as possible. The participants were asked to play under internal (focus on fingers), external proximal (keys), external distal (hammers), and external distal (sounds) conditions. On a transfer test, the participants were asked to reverse the tone sequence. The findings indicated that a more distal (sound or hammers) focus produced better results than internal (fingers) or external proximal (keys) focus.

Several researchers have investigated the effects of attentional focus on voluntary force application using hand, tongue (Freedman et al., 2007), or foot (Lohse, Sherwood, & Healy, 2011) tasks. Lohse, Sherwood, & Healy (2011) enlisted 12 subjects. All subjects were asked to complete a 30% of maximum voluntary isometric muscle contraction of the foot (plantar flexion) under internal (focus on contracting calf muscle) and external (focus on the force applied to the platform) conditions. The researchers found that the external condition resulted in a more accurate application of force in the task. In addition, EMG readings indicated a significantly greater muscle activation in the antagonist muscles with an internal focus of attention. There was no difference in the activation of the agonist muscles. In sum, the findings supported the researcher's theory that an external focus of attention would lead to greater performance as well as more efficient recruitment of motor units. Additionally, it appears that tasks related to speed, endurance, and force modulation support Wulf's (2013) conclusions indicating external cue advantages for performance.

Accuracy tasks

Many studies have investigated accuracy in hitting a target. In basketball, Al-Abood et al., (2002) looked at how attention to movement dynamics (internal cues) would compare to a focus on movement effects (external cues) in a free-throw shooting task. Further analysis revealed that the movement effects (external) group showed a significant improvement in outcome scores between the pre-test and post-test. In another free-throw study, Zachry et al. (2005) investigated free throw accuracy using internal focus (wrist motion) and external motion (basket) conditions. For both groups, EMG data were recorded with biceps brachii, medial triceps brachii, and medial deltoid of each participant's shooting arm. The results show that accuracy was greater for the participants with an external focus of attention. In addition, EMG activity in the biceps and triceps muscles was lower with an external focus relative to an internal focus, indicating less "noise" in the motor system and a more efficient movement.

Similarly, accuracy in dart-throwing has been demonstrated to increase with an external focus (Lohse, Sherwood, & Healy, 2010; Marchant, Clough, & Crawshaw, 2007). These effects seemed to be even stronger when the focus was more distal (i.e., on the bullseye) rather than proximal (i.e., the trajectory of the dart; McKay & Wulf, 2012). This "distal advantage" has been identified by McNevin, Shea, and Wulf (2003), although Wulf and Prinz (2001) argued that there must be an optimal "intermediate" external distance beyond the movement itself, but not so distal that degradation of performance occurs due to a reduced association with the movements producing the effect. Wulf, Mercer, McNevin, and Guadagnoli (2004) indicate that in sum, the literature confirms a 'smart' motor system that optimizes the control process based on the performer's desired environmental effects through a distal, but not too distal, target.

In a beanbag toss test measuring accuracy, Chiviacowsky, Wulf, and Avila (2012) found that mentally challenged children learned to toss bean bags more accurately when they focused on the movement of the beanbag rather than the movement of their hand. Saemi, Porter, Wulf, Ghotbi-Varzaneh, & Bakhtiari (2012) had similar findings using a sample of 10-year old children with attention deficit / hyperactivity disorder. Wulf et al (2010) used a sample of 10-12-year-old children in soccer throw in tasks, providing feedback with internal or external cues on a 100% (every) or 33% (every third) basis. Their findings indicated that external focus feedback after every trial (100%) was more effective on immediate and delayed transfer tests without feedback than external intermittent feedback (33%) or internal focus (100% or 33%) groups.

In a volleyball serving task Wulf, McConnel, Gartner, & Schwarz (2002) found that feedback provided with an external focus of attention was more advantageous than feedback criteria provided with an internal focus of attention. In contrast to the majority of previous studies, the researchers used a population of experts and novices instead of beginners. The researchers also provided movement scores, which also indicated that an external focus of attention was more effective than an internal focus.

In a soccer kicking task, Zachary (2005) found that novices benefited from an external focus of attention while experts showed no significant performance change between attentional foci. Novices also showed higher co-contraction indices during the swing phase of the kicking motion. It is presumed that co-contraction during the swing phase would lead to a more rigid (stable) and desirable form for transferring kinetic energy from the leg to the ball. Zachary (2005) interpreted this as further evidence that an external focus of attention induces a more automatic control of the motor system. Interestingly, Wulf, Hob, and Prinz, (1998) argue that internal cues tend to cause an inefficient (co-contraction) and less precise (as measured by outcomes). However, in Zachary (2005) it's clear that some movement patterns (kicking) are better served by a "freezing" of joints to produce a more efficient movement, indicating the somewhat domain-specific nature of "efficiency". Golfers, for instance, are often asked to "freeze" their wrists while putting but told to relax their wrists on full swings.

Zachary et al. (2005) sought to investigate the movement efficiency of a basketball free-throw task using electromyography (EMG) comparisons of external and internal cues. The results indicated that an external focus was advantageous from an accuracy standpoint. In addition, the researchers found that EMG activity of the biceps and triceps muscles was lower with an external focus of attention, suggesting that an external focus enhances the movement economy and reduces the "noise" of the motor system. The efficiency shown by the motor activation patterns in Zachry et al (2005) is consistent as we look at the literature as a whole.

Accuracy tasks in golf

Several studies have investigated the use of attentional focus on golf tasks beginning with Wulf et al., (1999). Wulf and colleagues recruited 22 participants without any golf experience to participate in a golf pitching task. The participants were divided into two groups. Both groups were instructed on standardized grip, stance, posture, and ball positions. One group was asked to focus on the swinging motion of the arms (internal cue). Specifically, participants were asked to keep the left arm straight and the right arm bent during the backswing, both arms being straight in the forward swing, and the right arm staying straight and the left arm staying bent in the follow-through. The other participants were asked to focus on the swinging motion of the golf club in a pendulum-type motion (external cue). Both groups were given feedback about their performance as needed. The practice phase consisted of 80 trials. The participants were asked to hit golf balls from a lawn surface onto a circular target with concentric circles with radii of .45m, 1.45m, 2.45m, 3.45m, and 4.45m. Shots were scored on a simple point system with shots in the smallest circle receiving 5 points, the next smallest circle 4 points and so on. A day later, all the participants returned for a 30 shot retention test. The results showed a significant improvement for the external group as compared to the internal group.

Seeking to expand on the Wulf, Lauterbach, & Toole (1999) study, Wulf and Su, Exp 1 (2007) introduced a control group with novices in a similar design. The same apparatus, task, and attentional cues were used as in Wulf, Lauterbach, & Toole (1999), but the control group was given no instructions. All groups performed 60 practice trials with the same grid (concentric circles) and scoring as in the previous study. A day later, participants performed 10 practice trials without any reminders or instructions. As was predicted, the external group outperformed the internal group as well as the control group. Experiment 2 (Wulf & Su, 2007) utilized a group of 6 skilled collegiate golfers (average handicap 1.3). The apparatus and task were identical except that participants used their own clubs and the radii of the concentric circles were smaller (.5m, .75m, 1m, 1.25m). All 6 golfers performed under all three conditions. The accuracy scores (average points) were 1.38 under the control condition, 1.29 under the internal focus condition, and 1.93 under the external focus condition. The effect of the external focus was significant, $F(2,10) = 9.66$, p. 9.66, $p = .005$. Post hoc LSD tests indicated that the differences between the external, control, and internal focus conditions were significant ($p<.05$). The internal and control conditions did not differ from each other.

Bell and Hardy (2009) sought to draw on Wulf, Lauterbach, & Toole's (1999) study by looking at how the proximity of an external focus of attention might affect the accuracy of skilled golfers performing a pitch shot. In their study, the researcher's assigned thirty-three skilled male golfers to internal, external distal, and external proximal foci. The participants executed five blocks of ten pitch shots, three in neutral conditions, and two in anxiety conditions. Participants assigned to the external distal group performed the best, while the internally assigned group performed the worst according to a mixed model ANOVA. Both findings were significant at a .05 p level.

Christina and Alpenfels (2014) sought to investigate how attentional focus might affect golfers in a swing path change. The goal of changing the golfer's swing path was primarily to get rid of their slice. Golfers in the internal cue group were asked to bring their elbow to their side in the downswing while the golfers in the external cue group were asked to swing their club from 8:00 o'clock to 2:00 o'clock with the help of an alignment rod angled to right field. A participant-selected cue allowed the participants to use whatever cue they preferred. The researchers used six irons (Study 1) and drivers (Study 2) with the above cues to show that participants learned and retained a more inside swing path with the help of the external cue as compared to the internal and self-selected cue. Golfers who were provided external cues also showed a significant increase and retention in the average carry distance.

Attentional Focus and Expertise

Although Wulf (2013) states the case is closed concerning the advantage of external over internal cues in attentional focus, others (Collins, Carson, Toner, 2016) have cited evidence of nuance that should not be discounted. In an effort to explore this view, a look at expertise more broadly is helpful. The most critical difference between a more general examination of expertise in motor learning and the body of literature cited by Wulf (2013) is the amount of practice. While Wulf (2013) cites mostly 1-3 day studies, Ericsson and Smith (1991) investigated the development of expertise over many years and found a variety of strategies used by experts that seems incompatible with the narrow research-driven conclusions Wulf (2013) holds. We began an analysis of attentional focus and expertise by focusing on the differences between novices and experts.

Chase and Simon (1973) utilized de Groot's (1946, 1978) work to build a framework comparing the learning strategies used by beginners and experts in a chess task (Bilalić, McLeod, & Gobet, 2008). Chase and Simon (1973) proposed that it was not the "hardware" of experts that allowed them to outperform novices, but rather their ability to chunk useful bits of knowledge together in domain-specific patterns of memory. This allowed experts to view a grouping of chess pieces on a chessboard and memorize the placement of the pieces with much greater precision as a result of their domain-specific familiarity with the patterns presented. However, when the chess pieces were placed on the board in a random placement it was clear that the experts had no significant advantage over the beginners (beyond their contextual domain-specific skills) since both groups were only able to remember four to five pieces on the board correctly. In essence, Chase and Simon (1973) theorized that the limits of short-term memory are relatively similar regardless of the level of expertise.

However, in contrast to Chase and Simon (1973), Ericsson and Smith (1991) concluded that extensive training may allow experts to acquire “hardware” and “mechanisms” beyond the capabilities of the typical beginners. Ericsson and Smith (1991) cite the abilities of unexceptional students to learn to remember long strings digits with extensive practice. Ericsson’s students, who all showed the ability to memorize at least 20 consecutive digits with practice, developed strategies to place short-term memories into long-term storage. As a result, the students challenged Miller’s (1956) theory that 7 digits (plus or minus 2) are the limit in short term memory tasks, a barrier that researchers at the time had accepted as a fixed ceiling. Based on these findings, Ericsson and Starkes (2003) proposed that over many months and years expertise could be developed by average performers through deliberate practice that would allow virtually any average adult to exceed normal ranges of short-term memory and processing, although the strategies used and the progress made by each participant would vary somewhat based on individual tendencies and baseline skills. In some cases, the ability to go beyond the norm is truly exceptional. For instance, one of Ericsson’s (1991) top students, Steve Faloon, was able to remember 82 consecutive random digits after hundreds of hours of practice. Later students have since eclipsed 400+ memorized random digits. It's worth noting that Miller's theory on working memory did not involve the extended time period and strategies of deliberate practice that Ericsson employed. Had Ericsson's students stopped at 1-3 days of learning random digit memorization, the students may not have developed strategies capable of breaking through the perceived barriers at the time.

Ericsson concludes that with 10 years and 10,000 hours of deliberate practice, expertise can be achieved. In the domain of sports, this typically occurs in the mid to late '20s and for the arts and sciences about a decade later (Ericsson, 2006). Although the general rule of 10 years or 10,000 hours of practice still seems to apply, the bar to reach expert status appears to be increasing as best practices for training becomes more effective. For example, the four-minute mile took until 1954 until Roger Bannister bettered the mark. Today, a sub-4-minute mile is routine in international events with over 5,000 runners completing the once seemingly impossible mark (Denison, 2003). The small differences between a fast runner and a world-class runner are subtle and incremental. Ericsson describes the process of skill acquisition between an expert and a near expert similarly. The difference can be either psychological, physical, or both. An example might be an expert's ability to respond quickly and precisely to the wide variety of situations present in a relatively novel environment. These incremental improvements epitomize the journey toward expertise. Since stable, systemic improvements are the goal, Ericsson (2006) argues that deliberate practice must be designed to constantly achieve the next level of mastery through continual training, testing, and the development of new techniques and strategies. This sort of practice requires full attention and concentration towards a goal that is slightly out of reach and the application of deliberate practice strategies (Ericsson, 1991).

Deliberate practice in virtually all domains has some common threads, beginning with the concept of desirable difficulty. Guadagnoli and Lee (2004) have demonstrated that one of the key aspects to making practice more effective is to make it more varied or more difficult until an appropriate "challenge point" has been reached. Thus, rather than letting performers attain a stable level of autonomous performance for an extended period of time, the best coaches create systems or environments that continually challenge the skill level of the performers' abilities. These contextual difficulties can include perceptual challenges, psychological challenges, or novel task situations that require the performer to add and develop a deeper repertoire of skills (Guadagnoli and Lee, 2004). In a similar context, Bjork and Bjork (2011) discuss the paradoxical difference between learning and performing, making the case that often deliberate practice, which can be difficult and slow, may induce superior long-term retention, whereas learning that feels easy and displays current performance gains may not show long term retention. Conditions that may expedite learning while concurrently dampening current performance include spacing practice, varying conditions, interleaving skills or subjects, and testing (Soderstrom & Bjork, 2015). In sum, it seems that in making practice conditions more difficult (to a point), performers learn more quickly.

From this "desirable difficulty" perspective we can see that Fitts and Posner's (1967) traditional notion of the stages of expertise may be somewhat limiting since it seems that expertise, at times, requires that a learner transition back and forth between cognitive and autonomous stages of learning as they seek to acquire new skills and then refine them (Ericsson, 2006, Shusterman, 2008). In essence, Ericsson (2006) and Shusterman (2008) argue that automaticity is not always the ultimate goal for continual expert improvement.

For instance, most of us walk in everyday life with a high degree of automaticity, yet few of us have reached expert status as walkers since we haven't trained extensively and deliberately as speed or distance walkers. The world's best walkers have chosen to deliberately train for speed or distance by employing new strategies and techniques to break through established patterns of automaticity. Ericsson (2006) suggests that when plateaus of performance are reached it is important for learners to avoid stable states of automaticity and instead develop new methods and skills, so as to avoid arrested development. It is possible that an internal focus of attention can be useful in training through states of a plateau. Oudejans, Koedijker, and Beek (2007) argue that an internal focus of attention may be critical when an athlete seeks to replace a suboptimal technique with a superior technique, or when a "reinvestment" in technique is needed to change a habitual pattern that is undermining performance (Beilock & Gray, 2007). In short, the nuanced view on expertise by Ericsson (2008) and others point toward a far more long-term pattern of skill and expertise and the intermittent use of external and internal cues that may not be compatible with the 1-3 day studies cited by Wulf's (2013) review.

In addition, high-level athletes have reported the advantages of focusing on the internal cues instead of external cues (Bernier, Trottier, Thienot, & Fournier, 2015;

Carson, Collins, & MacNamara, 2013; MacPherson, Collins, & Morriss, 2008; Nyberg, 2015; Orlick & Partington, 1988; Robazza & Bortoli, 1998). Furthermore, anecdotal evidence suggests that golf instructors still rely heavily on internal cue instructions. For instance, a typical Golf Digest publication relies on internal cues for over 60% of its tips to readers (Tarde, 2020). Outside of golf, physical therapists were found to use 95.5% internal cues when working with stroke rehab patients (Durham, van Vliet, Badger & Sackley, 2009). The substantial divide between the 1-3 day studies that represent the literature reviewed by Wulf (2013) and expert anecdotes highlighted above indicate a gap in the research.

Gaps in the Research

Cue Choice

One explanation for the gap between theory and practice is a systematic bias of cue choice. Cue relevancy is a critical factor in the design, implementation, and outcome of a study. Wulf (2013) stated that cues for internal and external foci in her studies have been deliberately chosen to be as similar as possible, often differing in only one or two words to avoid confounds with other variables (e.g. 'focus on the swinging of the arms' versus 'focus on the swing of the club'). Yet, similar word choices might elicit very different movement patterns and outcomes. In addition, the wording of these cues may be overly wordy and confusing to study participants (Wulf, 1997; Wulf, 2007) or lack a biomechanically accurate description (Wulf, 1997; Wulf, 2007; An, Wulf, Kim, 2013).

For instance, An, Wulf, Kim (20013) examined the effect of using ground force cues to influence X-factor stretch and driver carry distance in a golf task. Unfortunately, the researchers used cues that could be interpreted differently enough to produce very different movement patterns. For the external cue, the researchers asked the participants to “push off the left side of the ground”. For the internal cue, the participants were told to “shift their weight to their left foot”. Such an ambiguous internal cue might lead some participants to think about moving their center of mass in one direction (to the left), which of course would not lead to a change in vertical force on the platform itself, but instead a translation of mass over the platform. A thorough biomechanical analysis would likely note the difference between the center of mass and the center of pressure and how easily these cues could lead to an invalid outcome through a poor interpretation by the performer. Although the results of An, Wulf, Kim (2013) indicated more carry distance, X-factor stretch, and higher maximum angular velocities of the pelvis, shoulder, and wrist than both the internal focus group and the control groups, it is hard to interpret the results given the ambiguous nature of the internal cue.

A second potentially irrelevant internal cue is used in a study performed by Granados (2010) who investigated internal and external cues in a putting task. Granados (2010) had participants in the external group focus on the back and forth swinging motion of the putter head. The internal cue focused on the swinging motion of the hands by moving them back a short distance and then swinging them forward in a straight line towards the target. The results of Granados’s study supported an external focus since participants from the external group putted more accurately. However, the internal cue

Granados chose is problematic from the standpoint that it's been proven that the motion of the hands and putter do not move in a direct line towards the target (Parker, 2017). Like virtually all side-on sports movements (standing to the side of the ball as opposed to straddling it), we find that the hands and putter move in an arc. In addition, it is very possible that in using the term “swinging motion of the hands” some performers might interpret this to mean a “freeing” as an opposed to “freezing” motion of the wrists, which most PGA teaching professionals generally warn against since it leads poor clubface control (the most important element to accurate putting).

A third questionable and perhaps more influential study in the field goes back to the earliest and most foundational academic work in the area of attentional focus. Wulf, Lauterbach, & Toole’s (1999) study is the most widely cited in the attentional focus literature on golf. Wulf’s (Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007) pitching studies ask participants to hit pitch shots with a 9 iron toward a target identified by concentric circles of various radii. Wulf divided participants into external and internal groups for the task and found that the external group performed much better than the internal group. However, while Wulf’s external cue directed the participant’s attention to the swinging motion of the clubhead in a pendulum motion (a somewhat questionable cue given the sub-optimal dynamic shaft lean this implies), the internal cue is much more poorly chosen. The internal cue asked participants to focus on the swinging motion of the arms. Specifically, performers were asked to “keep the left arm straight in the backswing, both arms straight at impact, and the right arm straight and the left arm bent in the follow-through”. The internal cue offered is wordy and complex, which might contribute to an excessive "load" on participants' working memory process (Poolton et al. 2006). The complexity and limitation of the cue arise because it asks participants to direct their attention at three separate phases of the action, while the comparable external cue focuses only on the swinging motion of the club. Kahnamen's (1973) research indicates the difficulty in comparing tasks that require different levels of focus (dual vs. single task). In addition, the internal cue used (Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007) appears to be biomechanically questionable since notable professionals often advise and demonstrate an alternative technique.

Figure 1 shows top PGA Tour players and/or coaches demonstrating different techniques with both backswing and downswing arm motions. Notice Rory McIlroy (right arm bent in follow-through), Dave Stockton (left arm bent in backswing), Jordan Spieth (right arm bent in follow-through), Tiger Woods (right arm bent in follow-through) all demonstrate divergence from the internal cue provided. In sum, Wulf's (1999, 2007) cue choice cannot be considered a superior technique if so many teachers and to players demonstrate such a different technique.

Figure 1: Illustrations of professional golfers showing arm bend patterns inconsistent with Wulf's (1997, 2007) internal-arms cue

Moreover, a survey of top PGA teaching professionals shows that few coaches viewed Wulf's (1999, 2007) internal cue as optimal, or even appropriate. Of respondents, 7 out of 8 said that they would "seldom/never" use the internal cue Wulf (1999, 2007) provided. Several teachers explained how it might lead to "flipping" the hands or a "hitting" motion that would be detrimental to a good chipping/pitching technique and solid contact. Others noted the complexity and wordiness would confuse a novice golfer. The only respondent who said he commonly used the cue stated that he would only use the cue for training the motion, but not expect it to be effective in a performance setting.

It seems plausible that Wulf (Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007) chose this internal cue in an effort to keep the wording of the internal and external cues similar, thereby limiting the confounding variable of alternative motor patterns caused by vastly different cues. Unfortunately, in describing the swinging motion of the arms these studies produced a cue that is both confusing and biomechanically questionable.

Length of Practice

The second research question being considered is the length of the study. Most of the studies discussed above, particularly in the area of golf, used a retention test 1-3 days after skill acquisition to demonstrate learning. In addition, the period of skill acquisition is typically also quite short (1-3 days). The short length of practice typically used in the literature stands in stark contrast to the extensive body of work that Ericsson (2006) explored in his work of expert learning. Coaches, after all, are much more concerned with how skills develop over weeks, months, or years -- not 1-3 days. Thus, there is a substantial disconnect between what happens in the real world and the available research. In addition, most novices who take up golf plan to spend dozens if not thousands of hours practicing the game, rather than only a few days. As cues become more familiar, athletes are more likely to understand and appreciate their usefulness (Mauer & Munzert, 2013). Thus, as much as possible, research should seek to mimic real-world scenarios through longer periods of skill acquisition (Christina, 1987; Christina, 1989).

Ericsson's (1991) work, in particular, stresses the deliberate practice processes performers utilize to develop new strategies that may take years to refine. Often, experts must cycle between phases of automatic and cognitive processes, which speaks to the difference between what might be considered learning and performance and the deep familiarity with the attentional focus strategies used.

In a performance setting, experts are more likely to focus externally, relying on well-honed automatic processes (Rotella, 2001). In a learning setting, experts might purposefully choose a new technique that requires more cognitive attention, perhaps such as a new internal cue like Hogan's "wrist cup" while they retool during the off-season (Hogan, 1985). Such a strategy is tantamount to a cycling back and forth between stages to promote movement proficiency and may be critical to expert performance (Gray, 2004; Ericsson, 2006; Shusterman, 2008). The implication of this longitudinal view of motor skill expertise shows us how learning and performance may operate differently when it comes to attentional focus, much as Soderstrom and Bjork (1992) point to the paradoxes of measuring latent learning, overlearning, and fatigue. Theoretically, if provided ample time to reach automaticity, changing an old motor pattern through the use of an internal focus may be a prudent part of an expert's practice as it may be a strategic way to add "desirable difficulty" while improving technique (Guadagnoli & Lee, 2004) even if short term performance may suffer. Unfortunately, this strategy may not test well in a short-term performance test because internal cues simply take a longer time to be effective because of their novelty and associated processing demands.

A similar theoretical viewpoint worth considering is the dual-task perspective. In normal everyday life, human actions are motivated by an external focus. James (1890) and Prinz (1987) contend that actions are triggered by their perceptual effects. A toddler reaching for a set of keys on a desk reaches with an external target in mind, without any attention to extending his arms and clasping his hands around the keys (internal cues). Adults unlock a door by focusing on turning the key, not by supinating their forearm to rotate the key counterclockwise. As such, when we ask individuals to focus internally, we are asking them to focus on the end result (an external focus) as well as the biomechanical causal factor -- in essence a dual-task. Given a large amount of research on dual-task learning (Pashler, 1994) it should not be surprising that an external focus is more advantageous to short term learning. Yet again, as Ben Hogan (1985) and research on expertise (Ericsson, 2006) shows us, internal cues can, over time, become automated and useful in changing motor patterns. Eventually, internal cues can form the bedrock of great technique and require little to no cognitive load, thereby freeing the performer up to focus on an external target in a competition (Hogan, 1985). In essence, the action-effect principle (Prinz, 1997) and constrained action hypothesis (Wulf et al., 2001; Wulf, Shea, & Park, 2001), though effective in explaining *performance* limitations of an internal focus in a short-term study, are limited in exploring the potential *learning* advantages of an internal focus over an extended duration of practice.

Summary

In summary, it seems evident that "expertise" is radically different from the practice length-limited literature on attentional focus. The long-term and often counterintuitive nature of expert learning which often includes internal focus and body awareness (Ericsson, 2006) may simply not be adequately captured by 1-3 day retention studies.

Purpose of Study 1

The studies in this dissertation were designed to test the effect of cue relevancy and amount of practice in acquisition on learning golf skills. Specifically, Study 1 was conducted to demonstrate the importance of picking an effective internal attentional cue (H_1). This was done by using a new internal putting cue "rocking motion of the shoulders" as opposed to the movement of the hands in the Granados (2010) study.

Purpose of Study 2

Study 2 tested the same hypothesis (H_1) as Study 1 by including both an old internal cue (motion of the arms) in a chipping task as well as a new cue (motion of the wrists). Study 2 also extended the practice time to test H_2. We hypothesized that a retention test taken after a pretest and 1 session of skill acquisition would not show a significant improvement for any attentional focus cue. However, we hypothesized that a second retention test taken after an additional 4 acquisition sessions later would result in an improved outcome for the "new" internal cue as compared with the "old" internal cue.

Chapter 3: Methods

General Methodology

Both Study 1 and Study 2 utilized students from the University of Minnesota who were enrolled in a Kinesiology Department "Golf" class. The groups in each study were selected by class section, not through random assignment. In theory, classes were fairly homogeneous in terms of prior golf ability and pretest skill levels. However, in Study 2 it was apparent that one class in particular had more skill than the other sections. This class section had several collegiate hockey players and a greater percentage of students with previous golf experience generally. Through random assignment of cue choice this class became the control group for Study 2. The inability to control group heterogeneity of class ability is just one factor of many that made both Study 1 and Study 2 "field studies".

The golf classes and the study took place at the University of Minnesota's golf course (Les Bolstad golf course). Standard beginner golf equipment in good but not new condition was used. The golf balls used were yellow striped range balls in good condition.

Turf conditions were fair to good although green speeds varied slightly day to day based on agronomic factors as well as wind, moisture, and temperature. The main green used was circular with a slight slope from back to front, typically 0-2 degrees. Chipping was done from the collar, which surrounded the green. The superintendent indicated that the greens typically stimped at 8 ft on the stimpmeter. Although small differences we noticed day to day as a result of green moisture levels it was clear that the greens had been cut every morning.

Study 1 Method: Putting Study

Participants and Groups

Thirty-three university students participated in the study. All students were enrolled in a University of Minnesota golf class (mean age = 22). The age range of the students in the study was 18-24 (m=21, f=14). Three of the students were left-handed; all students provided informed consent to participate and the study was approved by the University of Minnesota's IRB. All students were asked about their previous golf experience. Seventeen students said they had never played or played very little, 12 said they had played a moderate amount of golf, and 4 said they played regularly or at a high level (breaking 80 occasionally).

Students in two class sections formed the two study groups, with 14 golfers in the earlier class section and 19 in the later class section. Students were not randomly assigned to a group. Instead, they were grouped by the class time they chose at registration. The earlier class time was provided external cue and the later class time was provided the internal cue.

The goal on the pretest and retention test was to make (in the hole) as many six-foot putts as possible out of 20 attempts. The dependent measure was the number of made (holed) putts out of 20 attempts. Students were paired up and sent to a hole to record their putting pretest score. The same hole was used later in the retention test for each pairing of students.

All golfers were provided a putter from the class if they did not have their own. The instructor provided basic information to each golfer about grip, stance, and alignment. A basic reverse overlap grip was recommended with the feet spread shoulder width, elbows bent 20 degrees, and hips hinged 20-30 degrees. The instructor checked each individual's set up to ensure that the golfer's eyes were positioned over or slightly inside the ball/target line. Afterward, the instructor demonstrated a 6-foot uphill putt 5 times and discussed the importance of optimal speed when putting. During the demonstration, the instructor stated that the goal speed of each putt was to roll the ball 18" past the hole if it was missed. The bent grass green was in good shape and rolling at a normal speed for a municipal golf course. The pitch, or gradient, of the green was between level and 1% (uphill). No side hill or breaking putts were used.

Procedure

Golfers were instructed to practice with the setup and grip they learned for 5 minutes trying to make putts 6 feet away from the hole. After the practice time golfers were asked to perform 20 putts from 6 feet away with a partner who acted as a scorekeeper. These 20 putts acted as a pretest. The scorekeepers kept track of each putt made or missed and recorded the cumulative number of holed putts. A binary measure (putts made or not made) was chosen since it would be very difficult to rate putts missed based on proximity/miss quality. This follows because it becomes subjective when comparing a putt that misses barely right or left of the hole that rolls 18 inches past and a putt that comes just short of the hole but on a poor line (missing right or left). There is no established way to compare speed vs. line when it comes to putting effectiveness. Both are important since balls rolling too fast tend to make the hole play smaller (capture rate).

Thus, the innate difficulties with ranking putts based on proximity and miss location ultimately seemed too complicated and subjective. It would, of course, be possible to follow Granados' (2010) design more closely and putt towards a resting endpoint target on a flat surface, but we chose to use an ecologically valid putting experience instead (real putting green, real hole).

After the 20-putt pretest, golfers returned to the instructor for another demonstration, this time with specific internal or external cues. The external cue group was asked to focus on the swinging motion of the putter. Specifically, they were asked to focus on the swinging motion of the putter in a pendulum motion, a common putting cue used by Granados (2010). The internal group was asked to focus on the swinging/rocking motion of the shoulders. This was a departure from the internal cue Granados (2010) advised since it focused on the shoulders instead of the "linear movement of the hands". To further enhance the cues, the instructor demonstrated the technique by hitting 5 putts while describing the respective cues. Participants were then paired up at random and asked to provide cues and reminders to their partners in accordance with the cues provided. Golfers were explicitly asked to only use coaching language related to their specific cue and/or the basic setup (grip, stance, posture) advised earlier. Participants practiced for 15 minutes with the new cue and then took a 15-minute mid-class break. When they returned, participants putted 20 balls at the same location as the pretest using their new cues during a retention test.

Statistical analysis

Two separate paired t-tests were performed on pretest and posttest results ,with the number of successful putts holed for each group (external and internal). Normality of the response variable was assessed with a Shapiro-Wilk test (Shapiro & Wilk, 1965) .In addition, a two-way ANOVA with repeated measures for factor "test" was conducted to assess the interaction of factors (test X group). These analyses were conducted in R environment (R Core Team, 2020) with function ***aov*** and ***t.test*** from the base library.

Study 2 Method: Chipping Study

Participants and Groups

A total of 68 golfers were asked to participate. All the students were enrolled in beginner golf classes at the University of Minnesota (mean age = 22). Their ages ranged from 18 to 32 years. A sports history form was completed by all participants for post hoc analysis. This was included for the potential for a post hoc analysis. All golfers provided informed consent to participate in the study and the study was approved by the IRB. There were 23 females and 45 males in the study, five of the students were left-handed. Students were asked about their previous golf history.

Students were grouped by the class section in which they were enrolled, with each of the four groups (classes) assigned a different attentional cue at random. Thus, students were not randomly assigned to an experimental group. Instead, they were grouped by the class time they chose at registration. There were 20 participants in the external cue group, 18 in the internal (wrists) group, 13 in the internal (arms) group, and 17 in the control group.

Procedures

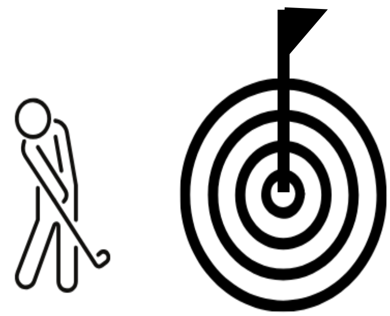
Golfers scored points based on the proximity of the end location of their shot (see table 2 below). Scorekeepers scored only shots that were struck solidly enough to carry onto the green. Thus, tops and thin shots were scored as 0 points because of insufficient carry distance onto the green or very poor contact. A final score for each participant was based on the total score for each block of 20 shots with 100 points being the most possible points if every shot was hit into the golf hole.

In the pretest, practice blocks, and retention test blocks, golfers were asked to perform a chip shot with a sand wedge from a fringe (fairway) lie near the edge of a circular green. Each block of shots consisted of 20 shots. Although this particular shot could easily be hit with a lower lofted club such as a 9 iron or pitching wedge, all participants were directed to use a sand wedge (56 degrees). The sand wedge was chosen for two reasons. First, it is the most commonly used club by accomplished players when chipping/pitching near the green. Second, a sand wedge, though perhaps a more difficult club choice for a beginner, should lead to better long-term technique since it requires the golfer to apply proper shaft lean at impact (a relatively counterintuitive concept since many beginners want to “scoop” the ball in the air). The golf balls used were standard range balls in good, but not new, condition. The target (a golf hole) was 8 meters away from the participants.

Table 1 : Scoring grid for Study 2

Finishing Position of shot	Points
In the hole	5
Within 3 feet radius	4
Within 6 feet radius	3
Within 9 feet radius	2
Within 12 feet radius	1

Figure 2: Diagram of Task for Study 2



All golfers were instructed to hold the club with the grip they learned and/or refined during the first 2 weeks of the golf class. Most golfers used the overlap or interlock grip, but some used the ten-finger grip. Grip recommendations were based on the instructor's recommendations. Golfers were asked to use a narrow stance with the feet approximately 4-8 inches apart (clubhead width or slightly more). A slightly open stance (aiming left) was recommended. At setup (address position), 60% of the weight was on the front foot with the hands leaning slightly towards the target. Golfers were instructed to stand close to the ball – about a grip length away or slightly more. Ball position was in the middle of the stance. A neutral or slight C posture is recommended with slight knee bend and approximately 20 degrees of forward bend from the waist. Before golfers were given any cues, all golfers performed a pretest consisting of 20 chip shots. After the pretest, golfers were given internal or external cues as described next.

Internal Cue Arms - The first-class section utilized the same internal-focus cue used by Wulf et al. (1999). The cue was described as the swinging motion of the arms by Wulf et al. (1999, p. 122). Specifically, "the left arm straight in the backswing with the right arm bending, both arms straight during the forward swing, and right arm straight and left arm bent in the follow-through". Before any shots were hit, students were asked to perform the swinging motion of the arms as described 20 times while holding a golf club. The instructor gave feedback on stance, posture, grip, or the swinging motion of the arms as necessary.

External Cue Club - The second class section utilized the same external-focus cue used by Wulf et al. (1999, p. 122) which was to focus on the "pendulum-like motion of the club" by swinging the club "freely and focus on the weight of the clubhead, the straight-line direction of the clubhead path, the acceleration of the clubhead moving toward the bottom of the arc". Like the internal-focus group, participants were given feedback on their execution of the cue as well as setup criteria.

Internal Cue Wrist - The third class section utilized a new internal-focus cue. Instead of focusing on the movement of the arms the new cue focused on the swinging movement of the wrists. Students were asked to focus on the swinging movement of the hands, locking their wrist in a position of slight flexion (flat left wrist) during the backswing, the downswing and into the follow-through. In an effort to learn the movement, students were asked to perform 20 practice swings while holding a golf club focusing on the swinging movement of the left wrist.

Control - The fourth class section served as a control group. The control group was taught as a normal golf class in which the instructor provided cues throughout the class appropriate to the individuals in the class. This included both internal and external cues as needed.

Class periods took place twice per week (Tues, Thurs). Class periods were 1.5 hours and 30 minutes were dedicated to chipping practice. Each class period and phase of data collection took between 2 and 5 days to complete. As a result, the total time of the study was about 3 weeks. The total class time dedicated to practice was 3.5 hours. Classes were encouraged to work on their full swing during class time but were not instructed to work on short game chipping or putting at all until the study was concluded, although they were encouraged to work on their full swing. Of course, since we were not able to control what participants did outside of class it was impossible to keep some participants from practicing short game pitch shots on their own or playing the golf course. As stated earlier, this is one limitation of a field study as the more interested class members likely played golf on their own on warm days.

Statistical analysis

To decide the appropriate model (ANOVA or ANCOVA), one-way ANOVA was performed on pretest scores. Normality was assessed employing Shapiro-Wilk and Levene test, respectively. Furthermore, the shape of the distribution of the response variable was assessed graphically with a quantile-quantile plot and a histogram. Since no differences were found between group pretest scores, a two-way ANOVA was conducted using retention and groups as factors (considering repeated measures for retention). ANOVA was performed with function ***aov***, available in the base library of the R environment for statistical computing (R Core Team, 2020). Pairwise *post hoc* comparisons were performed with functions in ***emmeans*** package for the aforementioned software.

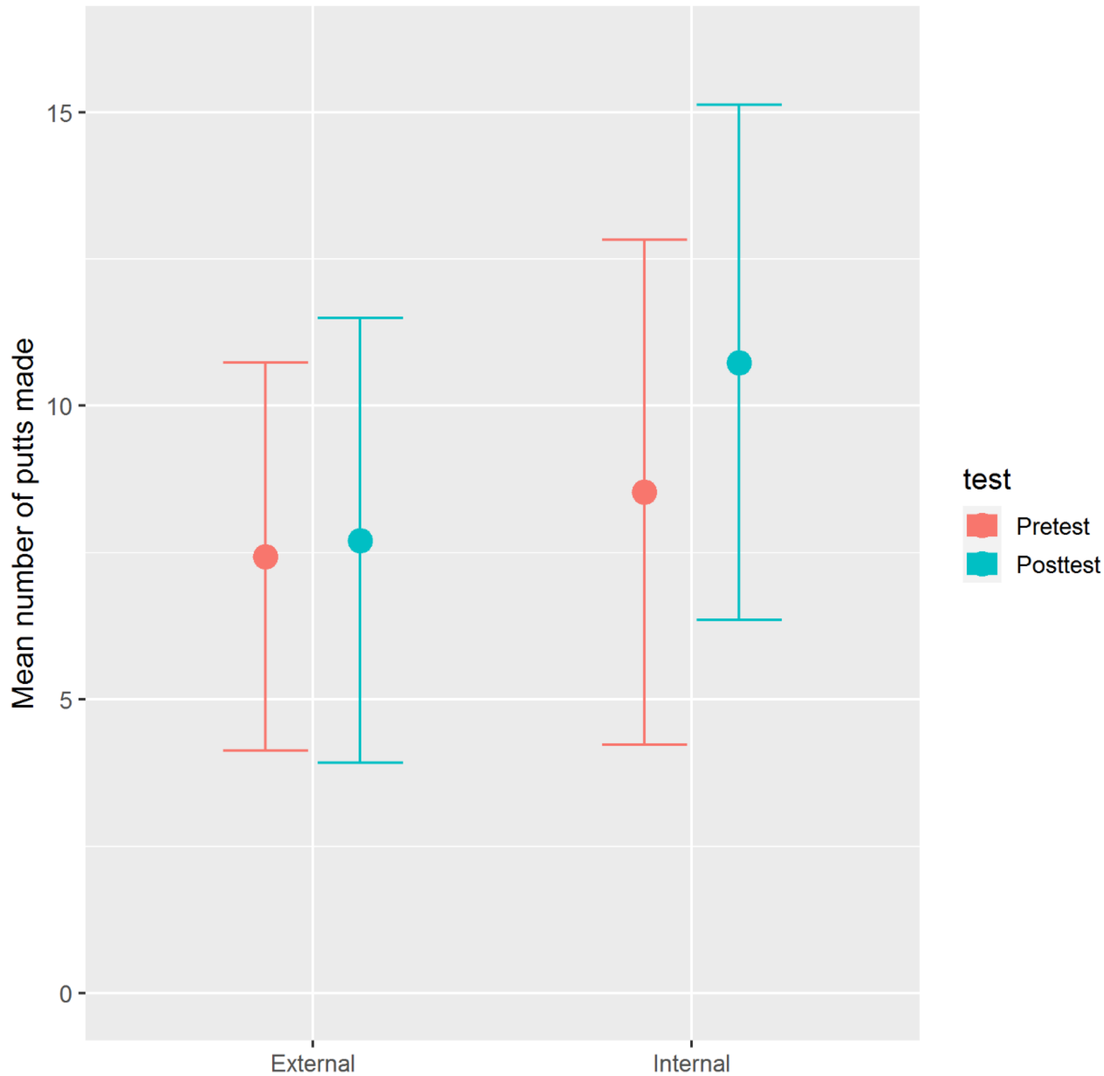
Chapter 4: Results and Discussion

Study 1 Results

Study 1 compared a new internal cue (rocking motion of the shoulders) to an external cue (swinging motion of the putter) in a putting task. The hypothesis for study #1 was that an internal cue would produce a higher mean score than an external cue, contradicting a similar study by Granados (2010) that utilized a biomechanically questionable (less relevant) internal cue.

Figure 3 shows the distribution of the mean scores for both groups in both the pretest and posttest. Except for external posttest distribution, the groups showed overlapping. The highest values were observed in the internal posttest group (mean = 10.74, SD = 4.39). External values were similar between pretest (mean = 7.43, SD = 3.3) and posttest (mean = 7.71, SD = 3.29), but slightly lower than internal pretest number of putts made (mean = 8.53, SD = 4.30). Although, Shapiro-Wilk test was significant (W = 0.9605, p = 0.034), histogram and q-q plot did not indicate a strong deviation from normality (Appendix 1). ANOVA failed to find significant differences for both factors, $F_{test(1)} = 0.009$, p = 0.926, and $F_{group(1)} = 2.366$, p = 0.129 and the interaction was also not significant, F(1) = 0.177, p = 0.675. However, the mean difference between pretest and posttest scores for the internal group was 2.21 (SD = 2.38). According to this two-tailed paired t-test, this difference was significant, t(18) = 2.89, p = 0.009. In the case of the external group, there was not a significant increase in the mean of posttest number of putts made (mean difference = 0.29, SD = 3.1), t(13) = 0.345, p = 0.736).

Figure 3 Study 1 - Mean number of putts made out of 20 attempts on a putting task. Bars represent the standard deviation.



Study 1 Discussion

The results of Study 1 indicate that the internal cue was more effective than the external cue since the mean score change (increase) for the internal group was significant according to a two-tailed paired t-test , $t(18) = 2.89$, $p = 0.009$. These results contradict both the Granados' (2010) and Wulf (2013) data who reported a near universal advantage of an external focus in all settings. The reason for the different outcome between Granados (2010) and the present study was the cue relevancy of the internal cue. As a reminder, Granados (2010) asked participants to ("move their hands in a linear motion toward the target"), which was biomechanically incorrect since the motion of the hands and putter cannot move in a direct line towards the target (Parker, 2017). By replacing Granados' (2010) internal cue with a biomechanically relevant cue ("rocking motion of the shoulders") in Study #1, the internal cue produced a superior result compared to the external cue. The significance finding for the internal cue used in Study 1 calls into question the consensus view on attentional focus proposed by Wulf (2013).

Study 1 has two limitations: First, the amount of practice and time between practice (same day pre-test and post-test) is a limiting factor since such a small time increment between the pre and post-test may measure performance rather than any permanent learning. Second, the improved internal cue (rocking the shoulders) was not compared directly to the older internal cue (motion of the wrists). Accordingly, study 2 extended both the length of the study time from 1 day to 3 weeks, added a control group, and also compared a new internal cue to the old internal chipping cues (Wulf 1999, 2007). This provided information on whether the type of cue or the time course was the more critical factor in the outcome.

Study 2 Results

Study 2 utilized a new internal cue ("firm left wrist") and compared it to Wulf's old internal cue (related to arm motion) in a chipping task (Wulf 1999, 2007). Wulf's old external cue (pendulum motion of the clubhead) group and a control group[1] were also used in the study. The hypothesis predicted that the internal cue ("firm left wrist") would result in a higher mean score than the other groups after 3 weeks of training. Figure 4 illustrates the mean pre-test scores for the 4 groups. Shapiro-Wilk results indicated non-normal distribution ($W = 0.9472$, $p = 0.007$), however, histogram and q-q plot indicated that this deviation was not serious (Appendix 2). Although the control group showed the highest mean score and the internal cues wrist showing the lowest mean score there were no significant differences between groups for these scores, $F(3) = 2.011$, $p = 0.121$.

Table 2 shows means and standard deviations for groups and retention levels. It appears that there was some improvement in all groups since posttest mean scores were higher, however, there was great variability. The tendency shown by groups regarding retention means scores were similar to the one observed in pretest scores. Two-way ANOVA for repeated measures showed significant differences only for groups (Table 2). *Post hoc* tests revealed significant differences only at the final retention test for the control group and the external and internal arms groups as both the external and internal arms group were significantly less than the control group (Figure 5, Table 3).

Table 2. Mean ± SD for retention and groups levels

Group/Retention	Pretest	First Ret.	Final Ret
Control	35 ± 18.08	40.33 ± 19.07	44.17 ± 19.22
Int-Arms	23.69 ± 14.10	30.55 ± 16.96	26.85 ± 16.71
Int-Wrist	21.78 ± 18,25	31.5 ± 20.86	35 ± 17.1
External	27.54 ± 15.78	28.19 ± 15.15	33.76 ± 13.09

Figure 4: Study 2 - Mean Scores out of 20 Attempts. Shots were scored 1-5. The maximum score of the test was 100 points if every shot was holed. Mean and 95% CI are displayed.

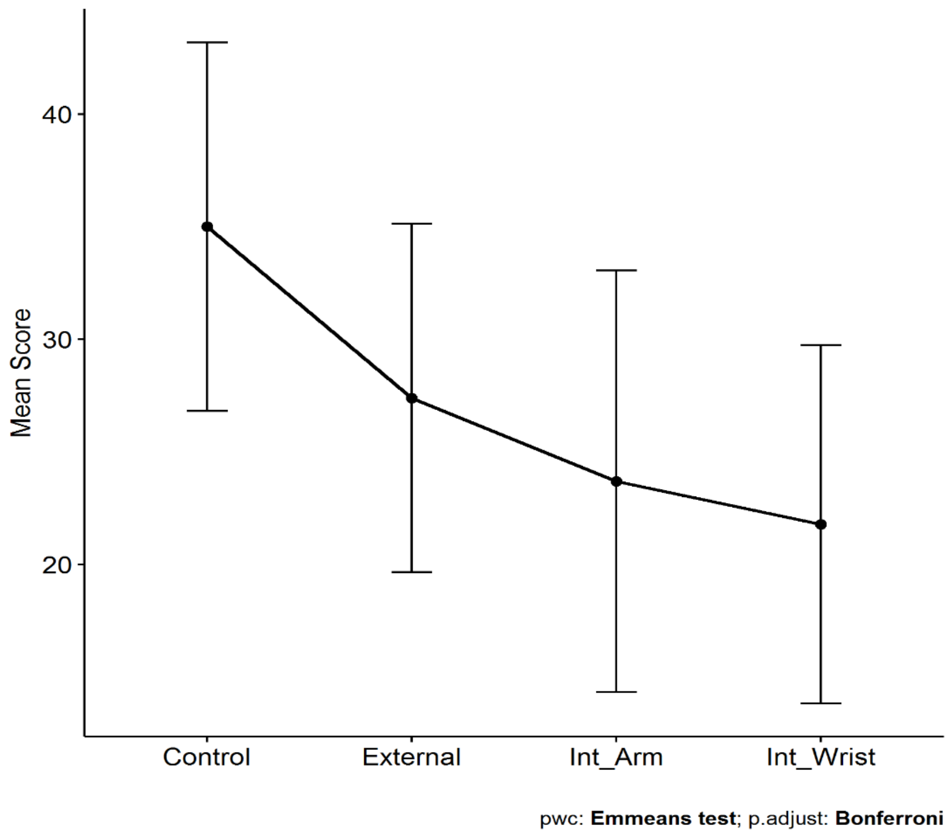


Table 3. Results of two-way ANOVA for repeated measures on factor retention

Source	D.F	SS	MS	F	p-value
Group	3	2504	834.7	2.754	0.045*
Retention	1	294	294	0.969	0.327
Group*Retention	3	343	114.2	0.377	0.769
Residuals	126	38194	303.1		

Figure 5: Study 2 – Mean Scores for Retention 1 (after 1 practice session) and Retention 2 (after additional 3 practice sessions) and groups. Lines represent 95% CI. Asterisks indicate significant differences.

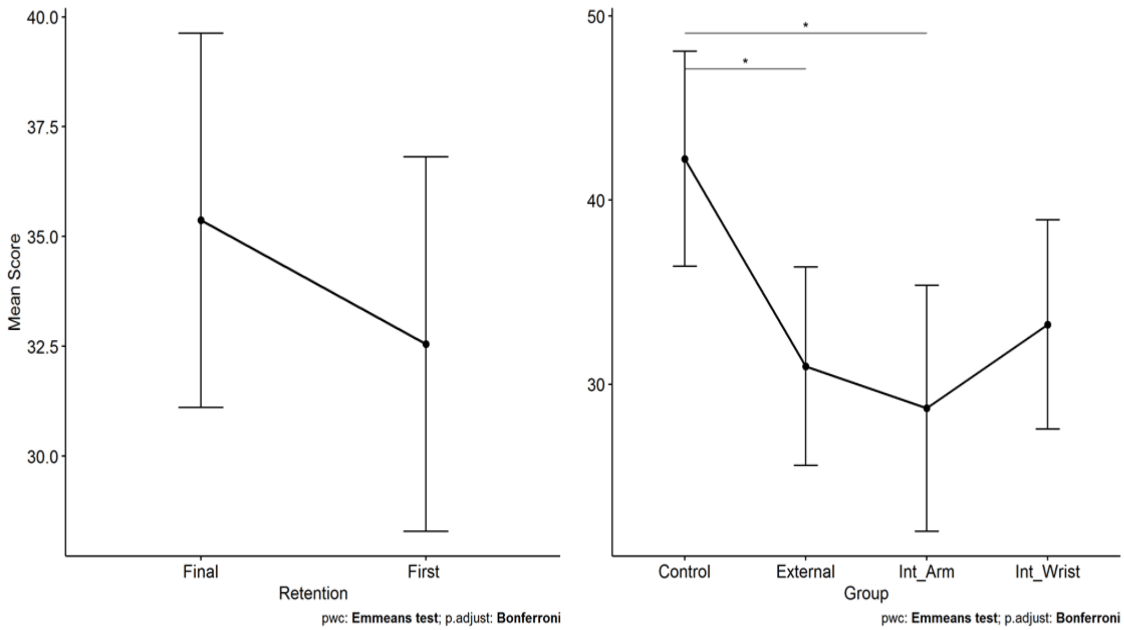


Table 4. Results of the *post hoc* pairwise comparisons on group means

Group 1	Group 2	df	Stat.	p	p. adj
Control	**External**	132	2.81	0.005	0.035*
Control	**Int_Arm**	132	3.02	0.003	0.018*
Control	**Int_Wrist**	132	2.18	0.031	0.184
External	**Int_Arm**	132	0.53	0.601	1
External	**Int_Wrist**	132	-0.58	0.567	1
Int_Arm	**Int_Wrist**	132	-1.03	0.307	1

Study 2 Discussion

In the case of Study 1, replacing a biomechanically questionable internal cue (used by Wulf (1999, 2007) with a cue commonly used by PGA instructors (rocking motion of the shoulders) led to an internal cue that outperformed the external cue. One limitation of Study 1 was that it did not compare a previously used internal cue (swinging motion of the hands) with a new and "superior" internal cue (rocking motion of the shoulders). In study 2, we sought to rectify this shortcoming by comparing the previously used (Wulf, 1999; Wulf, 2007) internal cue: 'Left arm straight and right arm bent in the backswing, both arms straight at impact, and left arm bent and right arm straight in the follow through', with a better internal cue, maintaining a flat left wrist (internal-wrists).

Wulf's (1999, 2007) original cue asked participants to focus on 3 separate phases of the pitching motion. This calls into question the relevance of the cue since the mental resources required to focus on 3 separate aspects of the swing concurrently are significant. A survey of teaching professionals (see page 39) indicated that these cues were overly verbose and potentially confusing. It is very likely the participants in Wulf (1999) and Wulf (2007) studies were confused as to the requirements of the cue. The processing requirements of Wulf's (1999, 2007) internal-arms cue might well have been substantially higher than the external cue employed in Study 2.

The new internal cue focused instead on the swinging motion of the hands with an intention to keep the left wrist in a position of flexion. The hypothesis predicted that the new internal-wrists would perform better than both the old cue internal-arms as well as the external cue. As described above in the results section, variance analysis did not show any reliable advantage for the new internal cue. However, comparing the results of Study 2 to Wulf's (1999, 2007) findings, no advantage for an external cue was evident! Furthermore, post hoc analysis showed that while the control group showed a significant improvement of the control group over the internal-arms and external groups while the internal-wrists group was not significantly different. This is an impressive finding for the internal-wrists groups since the control group was instructed with the best combination of teaching methods available to an experienced teaching professional and both groups performed better than the other groups. Had Study 2 been performed without a control group it is possible that a significant result would have been found for the internal wrists group.

The strength of the control group may have also been bolstered by the higher level of the talent in the group as it was composed of several DI hockey players and a few other DI athletes. This group improved by 9.17 points from pretest to final retention, but started with a high baseline. The internal-wrist group improved even more (13.22 points), and were not statistically different than the control group.

Chapter 5 : Conclusions

Summary and Conclusions

Study 1 and Study 2 hypothesized that a well-chosen internal cue could be more effective than an external cue. The results from Study 1 and Study 2 support this hypothesis since both studies showed examples of internal cues outperforming external cues. These outcomes indicate that cue relevance has a critical bearing on cue effectiveness, particularly when confusing or biomechanically questionable cues are used. Thus, Wulf's (2013) literature review which asserts that external cues are superior in nearly every situation is inaccurate. A biomechanically inaccurate or confusing internal cue, which must be considered less relevant, can critically weaken the study results (Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007; Granados, 2010; An, Wulf, & Kim, 2013). Hence, we can infer that attentional focus cues function on a continuum with the likelihood that some internal cues are better than external cues and vice versa. Context and nuance, as in most areas of motor learning and performance research, are critical.

In study 2, we also hypothesized that a longer practice time for skill acquisition would present an advantage for a well-chosen internal cue. In Study 2, the ANOVA analysis failed to support our hypothesis. However, failure to yield a statistical difference from pretest to first and final retention is noteworthy since it conflicts with the predominant theory assuming an advantage to an external focus (Wulf, 2013). Furthermore, the post hoc analysis indicates that only the internal-wrists group achieved the same statistical mean score as the control group at the final retention. Both the external and internal-arms groups mean scores were significantly less than the control group.

From a practical perspective, the findings of short-term studies are limited if the long-term studies show divergent outcomes. As Ericsson (2008) and others in our literature review have indicated, the learning process is long and complicated for top performers. Anecdotal evidence from Hogan (1985) and others (Ericsson, 2016) indicates it takes many years to master a skill. This process of mastery involves moving in and out of states of automaticity in an effort to "reinvest" in new techniques (Ericsson, 2008) often with the use of internal cues, such as Hogan's "cupped left wrist". If these cues were tested after only a 1-3 day retention and minimal practice, we may find that they would not perform well since internal cues tend to take more time to automate (Wulf, 2013). And yet it seems that coaches, teachers, and players have employed internal cues in training methods effectively over many months and years. Given that a great majority of the literature on attentional focus relies on 1-3 day retention studies (Wulf, 2013), we should question the validity of these results in a real world setting. As hypothesized earlier, once internal cues become more familiar and automatic, they might take on a more efficient and predictable level of performance.

By investigating this line of research with extensive practice time we may find higher level of agreement with reports of athletes utilizing internal cues and body awareness with success (Hogan, 1985; Bernier, Trottier, Thienot, & Fournier, 2015; Carson, Collins, & MacNamara, 2013; MacPherson, Collins, & Morriss, 2008; Nyberg, 2015; Orlick & Partington, 1988; Robazza & Bortoli, 1998; Ericsson, 2008). It is also possible that the terms “internal” and “external” become less important as the relevancy of the cue becomes a more critical factor.

Based on our findings, it seems that both objectives in the present study have been met. Based on the results and discussion of Study 1 and Study 2, the following conclusions are warranted:

1. The relevancy of an attentional cue is critical. Overly verbose, confusing, or biomechanically incorrect cues may invalidate the outcome of a study. Whether they are internal or external may be less important than the relevancy of the cue.
2. External cues have a short-term testing advantage as a result of the constrained action hypothesis (Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001). However, as practice time increases internal cues become increasingly effective. The only way to fully understand the importance of attentional focus cues is to record progress as a function of increased practice time.

Limitations

First and foremost, both studies were “field experiments”, with several variables that could not be controlled. There were some days in which the early morning classes had to deal with colder temperatures for practice or testing. There were also some warm and windy days on which the greens dried out more in the afternoon. In addition, since Study 2 was a chipping task, the grass was generally more trampled for the later class sections, particularly when the grass was wet. All these variables were difficult to control for, as is typical with field research.

Additional limitations exist for both Study 1 and Study 2. In Study 1, we did not include the original (Granados, 2010) cue, which asked participants to move their hands in a linear direction. There were concerns that adding the third group (old-internal) would have decreased sample size substantially. However, had the original internal cue been included (swinging motion of the hands) we could compare cue quality of the new and old internal cues directly. Without a direct comparison between the internal cues we cannot conclusively know that the new internal cue was superior to the previous internal cue, only that the experiment had a different result. Even so, the significant improvement for the internal group as compared to the external group is an important finding as so few studies support an internal focus.

Another limitation of Study 1 was the short time period between pretest and retention. By conducting the pretest and retention on the same day, we may be measuring a practice effect or a performance cue rather than learning. Although an advantage for the internal cue in a performance test of this kind is still an important finding, it doesn't necessarily support our learning advantage hypothesis of internal cues in certain settings over a longer time period.

In addition, it could be argued that the "pendulum" motion prescribed as the external cue in Study 1 is biomechanically questionable since the backswing and downswing time in a putting stroke do not mirror a pendulum motion exactly. Instead, a putting stroke arcs slightly inward on the backswing and outward slightly on the downswing. If a more appropriate external cue was considered we may find that the internal and external cue perform more similarly, or that the external cue may in fact be superior. This of course would lend credence to the hypothesis that cue quality influences the outcome of a study.

Regrettably, the same biomechanically incorrect “pendulum” motion is described in Study 2 for the external motion of a chipping stroke since it has been used as the precedent in previous experiments (Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007). As with Study 1, a pendulum motion during a chipping stroke is inaccurate given the arc of the club around the body. In fact, a pendulum motion for chipping is probably even more inappropriate for chipping than putting since the shaft lean (forward hands at impact) is more exaggerated.

Another limitation common to both Study 1 and Study 2 is that the participants were not randomly assigned. This “class section” assignment led to different baseline scores between groups that were problematic. In particular, the control group in study 2 displayed a much higher pretest than the other groups (35 vs 23.69, 21.78, and 27.54). By chance, this group happened to have more Division I athletes than the other groups, several of whom were hockey players. Such a critical difference of group backgrounds may have reduced our ability to find a significant result with the internal-wrists group.

Future Research

In spite of the limitations outlined above, the results of both Study 1 and Study 2 are encouraging. Both studies indicate the need to reexamine cue relevancy and the amount of practice time. The next natural line of inquiry would have to do with a difference between training for learning vs. training for performance. For example, a golfer that had a golf tournament tomorrow would very likely train differently than a golfer who had 6 months to prepare. In much of the literature, terms of learning and performance have been used nearly interchangeably, which may be problematic since learning can only be inferred from performance. Yet, paradoxically, learning can occur while performance does not, and vice versa (Soderstrom and Bjork, 2015). It is possible short duration studies utilizing internal cue studies might reflect this trend of poor testing married with concurrent learning. Thus, recommendations for training protocols may differ depending on the short vs. long term time frame or the need to reinvest in a new technique or cycle between stages of learning as (Ericsson, 2016).

We hypothesize that internal cues may be more effective in certain situations for training athletes over months and years since they may allow for a more precise and detailed breakdown of technique, particularly in areas when motor equivalence is a difficult match with a relevant external cue. Much of Ericsson's (2008) work on expertise seems to point toward the varied and relatively exploratory nature of training for expertise in a similar way. Specifically, the idea of consciously choosing to break down technique to a cognitive stage while retooling may be useful. A great example of this is the concept of a flat (flexion) or cupped (extension) left wrist at the top of the golf swing. This left wrist cue is a simple cue that golf instructors have been using with students to open or close the clubface for decades. Incidentally, this is the exact same internal cue used by Ben Hogan, which became golf's top "secret tip" of all time. The advantage of this type of internal cue may relate to the fact that golfers can't look at the clubface when making this change, which makes an external cue (closing the face) much more difficult. Future research may find that internal cues can be more effective even in performance situations when the performer is unable to actively see the effect of the movement (i.e., altering the clubface at the top of the backswing while looking at the golf ball).

As a golf instructor myself, with over 20,000 hours of teaching experience, I believe I can quickly tell which cues will be most effective with a particular student in a certain situation. In general, I often start a new student off with external cues because performance results tend to be best fastest with external cues since internal cues often take longer to assimilate. In addition, for golfers with an athletic background such as baseball or hockey, external cues directing focus toward the ball or the club tend to be incredibly effective. This may follow because athletes with this "hand eye" background can quickly manipulate an external object by recruiting a set of motor units critical for the task at hand. These athletes don't need to know how to move their body parts, just what to do. In understanding the external goals of the task, they are efficiently able to change motor patterns to meet the demands of the task, in full support of the CAH.

In other cases, my experience tells me internal cues are more effective, particularly in situations where a wrist angle or spine position (extension or flexion) is sub-optimal (as Hogan describes) and motor equivalence is not easily achieved with external cues. Gymnasts and dancers, for instance, tend to be highly skilled at using internal cues to quickly change technique, perhaps because they have been coached with internal cues more in the past. Future research should look to see how learners with different backgrounds may learn more effectively with divergent attentional foci.

One area where there is general alignment between research and practice in attentional focus is in a performance setting. Sports psychology and golf psychology have for many decades championed the benefits of a target (external) focus (Nilsson, Marriott, & Sirak, 2005; Rotella, 2001) in a competition/performance context. Legendary golf coach Harvey Penick (1992) was perhaps the first to instruct students to "take dead aim" and focus intently on the target instead of mechanics more than 50 years ago. Cumulatively, this evidence points towards an advantage for external cues (target focus) in a performance setting, but not necessarily in a learning/practice context.

Future research should investigate this training/performance difference with longer duration studies as well as comparing groups of learners who switch from an internal focus to a target (external) focus as they near a key performance event since this is the most typical pattern of training periodization. This would more precisely mirror the best practices advised by coaches and sports psychologists (Rotella, 2001). To verify and study this process of switching attention researchers should track an athlete's attention through self-report or directly with EMG activity e.g. (Kal, van der Kamp, & Houdijik, 2013).

In addition, it's possible that further research would find that athletes can maintain some level of focus on both internal and external cues at the same time. For example, a golfer could focus on left wrist flexion at the top of the swing while also changing a swing path by focusing on the direction of the clubhead as it passes through the ball. Nicklaus often talked about using up to 4-5 swing thoughts while playing, utilizing both internal and external cues (Nicklaus, 2007). Furthermore, we may find that experts are able to hold more cues in their mind at the same time than novices. Perhaps the number of "cues" is more critical than the internal/external nature of the cues, particularly with beginners. In sum, there is so much yet to consider regarding attentional focus.

Over time, best practices emerge in every field. Golf, as we have highlighted, is no different. What makes golf so fascinating to the outside observer is how poorly the best practices of golf teaching professionals and anecdotal evidence from golf's champions align with the current literature on attentional focus. In conclusion, it is hoped that future research will be able to bridge the gap between the considerable body of literature built on 1-3 day studies and the real-world experience of expert and novice athletes which point toward a more nuanced approach to internal and external attentional foci. Perhaps in time we will find that Hogan's secret represents an approach to motor learning that can be useful to all learners.

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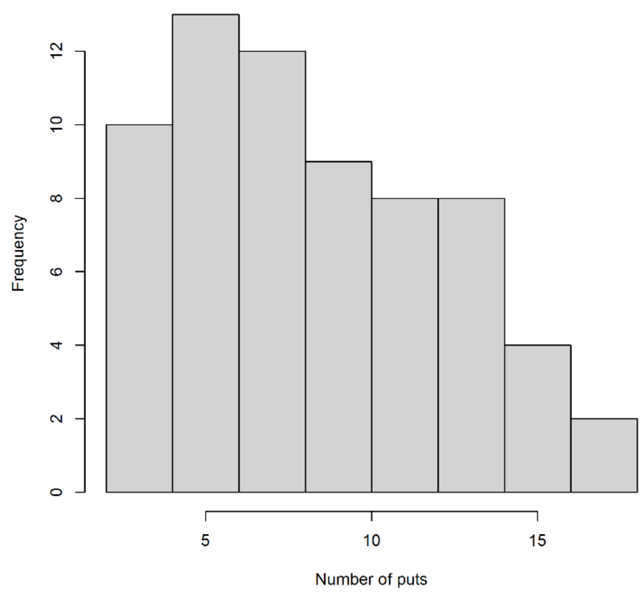
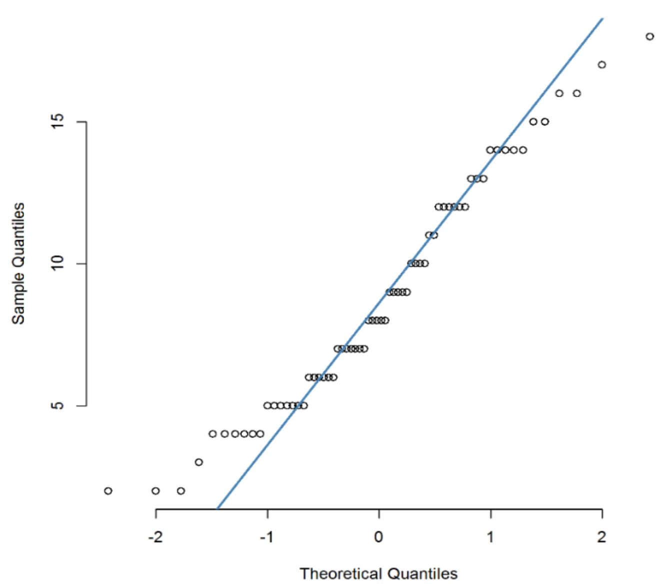
Appendix A

Study 1: Histogram of Putts Made

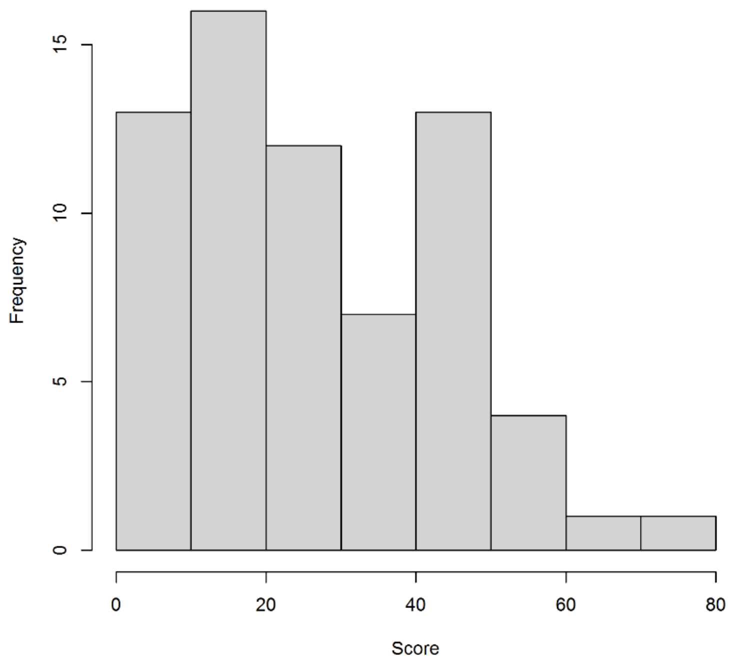


Study 1: QQ Plot



Appendix B

Study 2: Histogram of Chipping Scores



Study 2: QQ Plot