Effects of expertise and implement on performance of a discrete motor skill

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

Faculty of Physical Education and Recreation

University of Alberta

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Abstract

Introduction: Expertise in motor skill develops through continued practice. Repetition of a task can lead to overall performance improving as well as an increase in the efficiency and effectiveness of a movement. Golf putting is an example of one such task that needs to be practiced in order to become an expert golfer. Both the force and direction of ball travel need to be controlled to produce successful performance and these can be affected by varying distance and putter type, as well as expertise levels. The counterbalanced putter is a new to market design which adds concentrated weight to the upper shaft of the putter to mimic the stability of the anchored putting stroke which is now banned by the PGA. It is not currently known how the weight characteristics of the new-to-market counterbalanced putter will affect kinematics or overall putting performance and variability of movement in comparison to a conventionally weighted putter. Few kinematic differences between experts and novices have been identified and variability has not been compared. Various changes in kinematics and performance have been identified with increasing distance but the variability has not been examined comprehensively.

Hypothesis: The ability to control the direction of the ball should improve with the counterbalanced putter compared to the conventional putter and performance should improve. It was predicted experts would show better performance and increased consistency with all variables related to force and direction control. It was also hypothesized the average and variability of force control variables would change with increasing distance and performance would decline.

Methodology: 10 novices (5 female, 27.2± 7 years old, 0-7 years experience, 0-2 rounds/year) and 10 experts (10 males, 38.9±18.1 years old, 10-35 years experience, 6-100 rounds/year, self-reported golf handicap 9.7 ± 3.9) randomly putted 15 times each with a conventional and counterbalanced putter to target distances of 3, 5, 7, 9, and 11 ft, for a total of 150 trials. Kinematic data was measured with Visualeyez (Burnaby, BC). Means and standard deviations were calculated for phase timing and amplitude, contact velocity, stroke length ratio, relative phase timing, face angle, putter head rotation, and impact point. Performance was calculated with binary and constant and variable error in lateral and horizontal planes. A 2-group by 2-putter by 5 distance MANOVA with repeated measures on putter and distance was used for analysis (alpha = 0.05).

Results: The counterbalanced putter produced better average backswing timing, face angle, impact point, and contact velocity while decreasing face angle, putter head rotation and contact velocity variability. Increasing distance showed changes in all phase timings and amplitudes, stroke length ratio, contact velocity, face angle, and impact point. The key difference identified between experts and novices was decreased variability in face angle, putter head rotation, and impact point in the expert group. Binary performance measures experts were always better than novices, regardless of putter but did show a slight decline in performance with the counterbalanced putter. Overall, constant and variable error increased with increasing distance and it was found stroke length does change with increasing distance. Trajectory analysis showed consistency increased with the counterbalanced putter for both groups for movement over the Y-axis. Relative timing was not changed by the use of a

different putter and did not change with increasing distance.

Discussion: The schema theory of learning is present within the task of golf putting as changing force and distance parameters did not affect the relative timing of the phases of putt, regardless of the expertise level of the golfer. Relative timing of phases appears to be individual and not an indicator of expertise level. The counterbalanced putter improves the consistency of movement in comparison to the conventional and this has been attributed to the counterbalanced putters weight characteristics. Experts need more practice with the counterbalanced putter but anyone who would like to increase their consistency in face angle, putter head rotation, and impact point, would benefit from the use of the counterbalanced putter. Both experts and novices needs to practice keeping the amplitude of the follow through twice the amplitude of the fore swing, at all distances in order to ensure enough force is applied to the ball at ball contact.

Preface

This thesis is an original work by Kateline Hladky. The research project, of which this thesis is a part, received ethics approval from the University of Alberta Research Ethics board, Project Name “Expertise in a discrete motor skill”, Pro00056877, July 6, 2015. No part of this thesis has been previously published.

Acknowledgements

I would like to take this time to extend my thanks to all of the people who were there for me while completing this degree.

Dr. Brian Maraj: Thank you for taking me on as a student. I had some idea about the area of research I wanted to pursue when I started but your passion bred a newfound love and curiosity for research in me. Your patience, love, and boundless energy were instrumental in my personal and academic development over the last few years.

I would also like to thank Dr. Craig Chapman and Dr. David Collins for sitting on my examination committee. Dr. Chapman in particular, thank you for your guidance during these last stages of the process.

I would also like to thank my colleagues in the PMB lab: Dr. Adrian Popescu, Nicole Roshko, Ran Zheng, and Felix Ling. Whether it was teaching me how to use equipment, giving me a hand as I developed my methodology, or helping me collect data, you all helped more than you can imagine. Thank you for being so willing to help me out in the last few years.

Oma, you are the primary reason why I chose to stay in Edmonton to do my masters. I am so thankful that I was able to be with you for your last few months. You remain on my mind every day and it is your memory that has fueled me through some of my toughest days in the last few years. I love you!

To the rest of my family, you will never know how much you have helped me to get where I am today. To my parents, Jane and Kip Hladky, thank you for always being there to push me even when I didn't want to be pushed and as never ending support through the rough patches. Sometimes being told to turn off the computer and sleep, eat, and exercise was really all I needed. Cole, Emma, and Julia, while you may not have any idea what I have been doing in school for the last few years, thank you for always keeping me on my toes and laughing around the dinner table and for the patience as I missed so much happening in your lives. And to the rest of my extended family, just your presence means the world to me!

To all of my new and old friends, thank you so much for being at my side during this journey of mine.

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Chapter 1: Introduction

Motor skills and the ability to move are fundamental to human functioning and expertise with these skills develop through continued practice. Task repetition and practice can lead to overall performance improving as well as an increase in efficiency and effectiveness of the movement. Motor skills can also be attained which allow an individual to perform in numerous sports. A large amount of research completed in regards to golf putting has focused on aspects such as attentional focus and other cognitive requirements involved with motor skill production. Golf putting is an example of a task that is an essential component in order to play an effective game of golf. Previous research has examined optimal putting kinematics of experts but expert-novice comparison is limited. Both force production and direction need to be controlled to produce successful performance and may be affected by varying distance and putter type or design, as well as the expertise level of the golfer. Firstly, the following chapter will highlight theories of motor skill learning and sporting expertise development. Subsequently, previous findings in regards to how expertise level, varying distances, and putter characteristics affect the accuracy and consistency of the putting movement and overall performance will be reviewed.

1.1 Motor Skills, Motor Learning and Expertise

Motor skills are fundamental to a human's ability to function in their environment. They are defined as skills in which both movement and outcome are emphasized (Newell, 1991). These skills are classified by the movement and the perceptual requirements, or the amount of information an individual has to attend to in the environment, when performing the skill. Movements are classified as discrete, serial, or continuous. Discrete skills have a distinguishable beginning and end and usually have a duration less than 5 seconds (Schmidt, 1975), such as throwing a ball, and continuous skills do not have a distinguishable beginning and end, such as walking (Schmidt & Lee, 2005). In contrast, serial tasks are a number of discrete tasks strung together, such as playing a piano. Perceptual requirements classify movements as closed or open skills. Closed skills are executed when the environment does not influence the pattern of the movement being made, such as bowling. In an open skill, the exact pattern of the motion executed is variable due to an unpredictable environment, like catching a butterfly or playing soccer. Skills are classified as being on a continuum between closed and open. Classification can also depend on the situation in which the task is executed (Schmidt & Lee, 2005).

Skills are also classified based on the way in which they are learned. These two classifications are phylogenetic and ontogenetic. Phylogenetic skills, such as walking and reaching and grasping, develop more naturally as part of human development and ontogenetic skills, such as any skills utilized in sport, are developed through deliberate practice and trial and error, not coming as naturally as skills such as walking (Newell, 1996). There are numerous skills that humans acquire and continue to develop throughout their lifespan. Walking, one of the first skills developed, is learned in stages, which include crawling, standing, walking with support and eventual unsupported walking. All stages include constant adjustment until the skill is mastered. Skills, such as reaching and grasping, are developed through trial and error as the learner generates the ability to reach their hand to the desired end point where they can grasp an object, such as a glass of water. It was initially thought development of ontogenetic skills was limited by genetically determined innate abilities of an individual and would eventually plateau and no longer improve (see Ericsson, Krampe, & Tesch- Römer, 1993 for review).

Other theories suggest skills in sporting contexts can be developed beyond a plateau, allowing for expertise to develop. These theories include those of Bryan and Harter (1897), Fitts' and Posner's three stages of learning (1967), Schmidt's schema theory (1975), and Ericsson's expertise-performance approach and 10,000 hours theory (Ericsson et al., 1993; Ericsson, 2006b, 2014). Ericsson (2006a) defines expertise as "characteristics, skills, and knowledge that distinguish experts from novices and less experienced people" (p. 3) and experts as individuals with consistently superior levels of performance on representative tasks within a domain.

Bryan and Harter (1897) completed one of the first examinations of motor learning over an extended period of time by examining telegraphy workers as they learned to both send and receive telegraphs. They found the ability of a person would plateau after a certain period of time with one kind of practice but further improvements could be seen if practice was extended (Bryan & Harter, 1897). Later theories, such as those of Fitts and Posner (1967), attempted to explain how this change in performance coming from practice may occur.

Fitts and Posner (1967) proposed three stages of learning a motor skill. The first stage is the early, or cognitive, phase in which the learner tries to understand the task. This is where the skill is acquired and developed by thinking through the skill and is broken down into parts so each part is learned separately. The learner must be provided with important perceptual clues, response characteristics and knowledge of results. In the intermediate, or associative phase, all of the previously learnt parts are brought together to form new patterns and performance gradually increases. The final, or autonomous, stage is where the skill is less influenced by cognitive control and other distractions but performance levels can still vary and possibly degrade after reaching this stage (Fitts & Posner, 1967).

Building upon the ideas of Fitts and Posner (1967), it was proposed the ability to execute skills within a class, and move towards the autonomous stage, came from the development of two schemas: the recognition schema and recall schema (Schmidt, 1975). A schema is a set of rules allowing for the appropriate recognition of a class of actions (Schmidt, 1975). Schmidt's schema theory states that feedback from every attempt, regardless of success or failure, will contribute to schema development and refinement (Schmidt, 1975). The recall schema acts to select the parameters required for successful action when presented with a situation where an action needs to be executed while the recognition schema compares the outcome of the action to the expected outcome in order to refine the schema for future attempts (Schmidt, 1975). The schema theory provided a solution to both a storage and novelty problem that arose within previous motor control theories. It was believed each individual action required a separate motor program or frame of reference but the central nervous system is not capable of storing that magnitude of information. The theories at the time could not explain novel actions being generated without the development of a specific, separate motor program for it.

Based on the schema theory, separate motor programs are not stored for every possible movement because there is a generalized motor program developed for every class of action instead (Schmidt, 1975). Within a class of actions there are different parameters developed which will change with increasing distance in order to generate the necessary force for that distance. There are also invariant features, while the exact amount of time it takes to perform a skill may change with changing distance, the relative timing of different phases of the movement should not change. While this has been disproven in some tasks (Gentner, 1987), invariant relative timing has been found in some bimanual tasks (Heuer, Schmidt, & Ghodsian, 1995). Every repetition of an action is supposed to strengthen the schema for the class and attempts have been made to manipulate the type and regularity of feedback information provided to the performer, in order to generate specificity effects, or increased performance levels in different members of a class. This has been attempted in a task such as pointing with a stylus, but all attempts have failed (Proteau, Marteniuk, & Lévesque, 1992).

Ericsson et al. (1993) sought to specifically look at expertise and related the total number of practice hours by musicians to expertise levels, finding those considered experts deliberately practiced for 10,000 hours. The expertise- performance approach was developed specifically in response to previous theories looking at skill development which failed to address how expertise develops in certain individuals in certain skills. Expertise had been initially proposed to be the result of over 10 years of practice in a skill but Ericsson et al. (1993) found the plateau in performance reached after 10 years could be exceeded with deliberate practice. They identified conditions for deliberate practice which include: repeatedly executing the task or skill, availability of immediate extrinsic feedback and knowledge of results, and motivation to pay attention to and exert effort on the task or skill (Ericsson et al., 1993).

The expertise-performance approach developed by Ericsson addressed deliberate practice and expertise in domains such as music and chess where primarily cognitive processes develop during 10,000 hours of practice (Ericsson, 2014). Sporting situations are very different but it has been acknowledged that expertise is highly domain specific and expertise in one domain may not transfer to another similar domain (Hodges, Starkes and MacMahon, 2006). Starkes, Deakin, Allard, Hodges, & Hayes (1996) looked at deliberate practice in wrestling and figure skating as well as team sports. It was found wrestling and figure skating, while requiring less overall hours, aligned with Ericsson's expertise approach and deliberate practice theories. Individual sports not requiring as much cognitive function may be different. The research of Hodges and Starkes (1996) questioned how much variance was accounted for with deliberate practice and highlighted the large difference between experts and novices in terms of visual search patterns when completing a task.

In summary, theories developed by Bryan and Harter (1987), Fitts and Posner (1967), Schmidt (1975), and Ericsson et al. (1993) have developed a strong basis for understanding skill development. This work was built upon by Hodges and Starkes (1996), Starkes et al. (1996), and Hodges et al. (2006) within sport but it is not known what processes allow skill to develop in an individual sport such as golf and more specifically golf putting.

1.2 Golf

As discussed above, expertise research has focused on such activities as music, chess, figure skating, wrestling, and soccer (Ericsson et al., 1993; Starkes et al., 1996). While team sports and open skills have received a lot of attention, the research on individual sports and closed skills is lacking (Hodges and Starkes, 1996). Golf is an example of an individual sport in which the perceptual skills can vary depending on wind and other elements such as terrain. Development of expertise in a sport such as golf requires training in aspects such as driving, chipping and putting (Hume, Keogh, & Reid, 2005). While elements such as wind speeds and terrain may affect the performance of a drive or chip shot, they do not necessarily affect the performance of the golf putt as much as elements such as distance to the hole, type of putter utilized and overall experience level with the task. To date, biomechanical assessment on maximizing force and accuracy has primarily been completed on the golf swing due to 17 clubs, of which 13 can be placed in the bag with a putter, being utilized for the swing while only one club is used for putting (Hume et al., 2005). The ways in which expertise has been examined in an individual game such as golf have largely been limited to cognitive processes involved with learning necessary skill for good performance. While golf could be considered to be a domain of skill, it may also be that each of the different aspects involved within the game, such as golf putting, make up their own domain.

Putting comprises 40% of the score in a round of golf (Pelz and Frank, 2000) and it is necessary to excel at this skill, or domain, in order to perform at a high level within the game. Putting is defined as “an impulse movement in which force is applied by a putter to a stationary ball” (Sim & Kim, 2010, p. 932). The primary goal of the task, and the only external constraint, is the ball entering the hole with as few shots as possible, focusing on accuracy more than force maximization (Delay, Nougier, Orliaguet, & Coello, 1997; Hume et al., 2005). The same movements will always be executed regardless of non-regulatory factors such as weather and green characteristics, making the golf putt a discrete and closed skill.

In golf, expertise has traditionally been defined with the use of handicap, which is the "measure of your potential golfing ability that enables you to compete equitably with golfers of differing ability." (Golf Canada, 2012). A golfer's handicap can be calculated by subtracting the par score or the number of strokes a player should ideally take on the course from the actual score and averaging as more rounds are played. A lower handicap is used to characterize experts and if calculated, novices typically have a higher handicap. Using a golf handicap to define expertise can be problematic because performance on different skills within the game influence the overall score of a round. For example, putting is considered to contribute to 40% of the game of golf (Pelz and Frank, 2000) and handicap does not account for this difference in score contribution. Putting is a multifaceted action that consists of three phases: the backswing, the fore swing, and the follow-through. The fore swing and follow-through combine to make up the downswing phase. Expertise in numerous aspects contributing to putting skill development such as green reading, aim, and stroke are necessary for success at the task (Karlsen, Smith, and Nilsson, 2008). Aim and stroke are of particular interest, due to their reliance on motor aspects, more than perceptual ability which primarily affects green reading ability and ability to judge the distance to the hole. The following variables have been identified as being important for force control: amplitude and timing of phases, stroke length ratio, and contact velocity (Delay et al., 1997). The three variables important for the control of the direction of the putt are face angle, putter head rotation, and impact point (Karlsen et al., 2008). **Figures 1.1** and **1.2** show the different phases and variables.

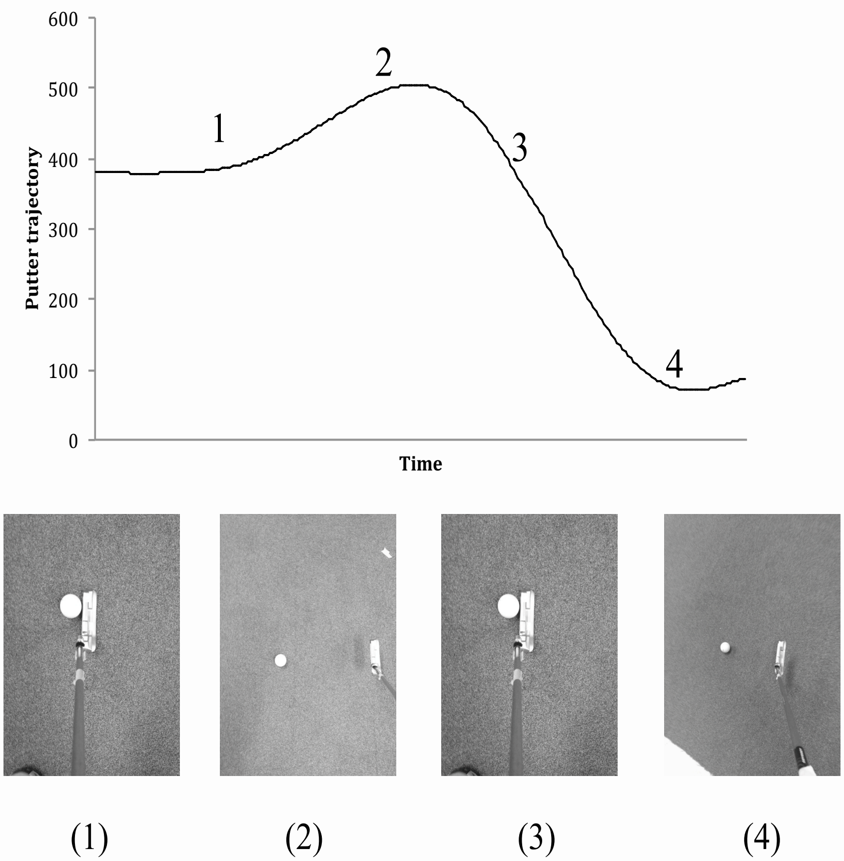

Figure 1.1. Putt Trajectory Phasing. Point 1 is address; the putter then moves through the backswing to point 2. The putter moving forward to point 3 makes up the fore swing, point 3 is ball contact. The movement from point 3 to point 4 is the follow through. The movement of the putter from point 2 to point 4 comprises the entire downswing.

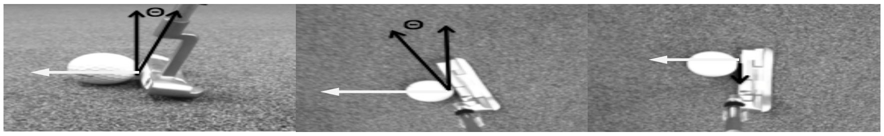

Figure 1.2. Variables effecting the direction of ball travel: face angle (left), putter head rotation (middle), and impact point (right). Yellow arrows indicate intended direction of ball travel.

The research on golf putting kinematics and performance improvement is fairly limited. Golf is a highly popular game and most information people have access to is non-scientific and written by professional golfers. Information provided in these resources, while easy to understand, conflict with each other and are generally based on personal experience and personally developed techniques of professional golfers.

In general, the suggestions made in popular literature vary, which makes it hard to discern what is important and how to practice for improvement. Therefore, it is important to focus on quantitative findings on various aspects of putting mechanics. Overall, the two most important components for completing a successful putt are force and direction control. An appropriate amount of force needs to be applied, in the correct direction, in order for the putt to be executed accurately (Sim & Kim, 2010). Golf putting is similar to other skills in which adjustments can be made in the movement until contact and outcome cannot be controlled once this occurs (Delay et al., 1997). Ball contact may be a specific event in the putting motion despite being the end point of force control over the ball and movement control after ball contact may still be important for success (Delay et al., 1997).

Scientifically, there have been a number of variables identified that may change the way in which the putter moves, but in some cases performance has not been found to significantly change. Psychological elements, such as anxiety (Hasegawa, Koyama, & Inomata, 2013) and attentional focus (Beilock, Carr, MacMahon, & Starkes, 2002; Beilock & Gonso, 2008; Beilock & Gray, 2012; Beilock, Wierenga, & Carr, 2002; Perkins-Ceccato, Passmore, & Lee, 2003), have been shown to contribute to changes in putting accuracy. Experts and novices have also been shown to process cognitive requirements of the task differently, which can change when groups utilize different implements (Beilock et al., 2002). Experts and novices grip the putter, visually prepare for the shot, track the ball, and coordinate eye and head movement with putter movement differently (Hung, 2003; Lee, Ishikura, Kegel, Gonzalez, & Passmore, 2008;Gonzalez, Kegel, Ishikura, & Lee, 2012). In particular, expert golfers do not follow the putter head as it moves through the backswing and forward through the fore swing and follow through, while novices heads move along with the putter (Lee et al., 2008, Gonzalez et al., 2012). Different weight transfer patterns have also been identified (Ball & Best, 2007a, 2007b). These different elements in the body and the putter movement can change but not prevent the ball going into the hole.

Overall, much of this previous research has examined golf performance with a focus on perceptual requirements, or top-down approach, while there has been little focus on the mechanics and its effect on performance. The approach used here is a bottom-up, or mechanical one, so as to look at the skill more extensively and ensure all avenues for performance enhancement are utilized. A small number of studies have quantitatively looked at the kinematic characteristics of putter movement which differentiate players as expert or novice, however few have examined variability in these measures affecting performance.

1.3 Variability

Variability is a measure of how consistent someone is with a movement (Schmidt & Lee, 2005). As previously discussed, there are many aspects which can change performance within a golf skill, but other aspects which can change at the same time may not affect performance. Eye tracking, weight transfer and other aspects can change but as long as the goal of getting the ball in the hole is achieved, the process of getting it in the hole can vary. Despite this, it is still important to examine variance, or consistency from one attempt to another, in the kinematics of the putter movement, in particular, because increasing consistency at particular distances should lead to increased performance levels. Looking at motor control in tasks such as golf putting require looking at how variance will respond as the result of the conditions, or constraints, on the task being changed. Within-subject and group variance should also be examined in order to determine differences between expertise levels. Examining variance in this way requires comparing the standard deviations from a large number of trials with constant experimental conditions (Marteniuk and Mackenzie, 1990). While variance occurring with changes in experimental conditions is important to examine, identifying invariance in elements such as the relative timing as manipulations in distance and putter type are made can indicate how strongly the skills' structure has been developed in the golfer.

1.4 Kinematic differences identified in previous literature

The studies detailed in **Appendix A** have identified numerous kinematic differences with changing distance, putter type, and differences between expertise levels using varied methodology. Studies have identified phases in slightly different ways and variables such as face angle, putter path, and impact point have been defined in various ways. Some of the kinematic differences are highlighted below.

1.4.1 Putter

Previous research completed by Gwyn and Patch (1993), Delay et al. (1997), Pelz (2000), Beilock, Wierenga, and Carr (2002), Schmidt (2003), Karlsen & Nilsson (2007), Karlsen & Nilsson (2007), Karlsen et al. (2008), Karlsen & Nilsson (2008b), Schmidt and Wrisberg (2008), Sim & Kim (2010), provide some indication of the kinematic and performance changes which may occur when two different putters are utilized, regardless of expertise level or distance.

According to the schema theory, the relative timing of a movement is considered an invariant feature of a motor program and should not change regardless of the distance or force parameters (Schmidt, 2003; Schmidt & Wrisberg, 2008). The stroke length ratio has also not been examined in various putter types so it is not known how different weight characteristics may change this variable. There is also no literature in regards to how the variability in this measure may change with various distances, putter types, or between expertise levels. Putters with different weight characteristics have been examined, while Sim and Kim (2010) primarily used the difference as a task constraint for the participant. The authors found general differences between putters during the downswing with the putter velocities being 0.69 and 0.73 m/s for the heavy and light putters, respectively. It was concluded that a heavier weighted putter head would result in an increased moment of inertia needing to be generated and higher velocities needing to be generated in order to reach the same distance as that of a lighter putter head (Sim & Kim, 2010). Shaft weight did not have a large influence on the initial ball speed for any given club head speed (Karlsen & Nilsson, 2007). Participants need to apply more force to the heavier putter in order to create the same club head speed and therefore, the same distance as with the lighter putter. The variability differences were not overly emphasized by the Delay (1997) study and it is also not known how contact velocity may vary with changing distance and with different putter types.

Karlsen et al. (2008) suggested a heavier weighted putter would result in smaller variability in all measures controlling the direction of the putt. A change in face angle could make it hard for golfers to ensure the ball is being hit on the proper point of the putter to achieve the correct direction of ball travel and the ball subsequently falling in the hole. When compared to mallet putters, blade putters produced significantly less putter head rotation (1.33° vs. 1.41°) (Karlsen & Nilsson, 2008b). These differences are also highlighted by Hladky, Roshko, and Maraj (2014). This study defined the putter path as the deviation in rotation of the putter about the Z-axis between address and contact. Testing of experts and novices found putter path variability to be 0.4° and 1.4° for the blade and mallet putter, respectively. It was determined that the putter path followed by the blade putter was less variable than that with the mallet, regardless of expertise level (Hladky et al., 2014). It has also been suggested a heavier weighted putter would result in smaller variability in the putter path (Karlsen & Nilsson, 2007). Sim and Kim (2010) also tested various putters and identified no significant differences in the mean impact point values. It has been suggested a heavier weighted putter will result in smaller variability in impact point (Karlsen & Nilsson, 2007). Taken together, it can be concluded the variability in direction variables such as face angle, putter head rotation and impact point should be smaller with the counterbalanced putter in comparison to the conventional putter and the mean values of these variables should not vary between the two putters.

In terms of varying putter type, some studies, including those of David Pelz (2000), have looked at the effects of the long putter on performance in comparison to the conventional putter at various distances. Gwyn and Patch (1993) found that there was no difference between the putters at 9 ft after practice. In combination with research completed by Pelz (2000), the long putter, a putter with a shaft of 45 inches or more, depending on the golfers height, has been found to be more effective on 3 ft putts, equal to the conventional putter at 9 ft, and less accurate at 20 ft and 40 ft (Hume et al., 2005 Karlsen and Nilsson (2007) found a light putter resulted in putts going significantly further than with a heavier putter but found no significant differences between performance with three various putter weights. There may be differences in force control variables created by changing the weight characteristics of the putter, these differences may not translate into a change in binary performance measures. Varying putter head shapes and putter shaft weights have been examined by Karlsen et al. (2007), Karlsen and Nilsson (2008b), Beilock et al. (2002), and Sim and Kim (2010) but actual performance changes caused by these differing characteristics were not examined in these studies. Sim and Kim (2010) manipulated shaft weight to create a task constraint and did not focus on its affect in an actual golf setting. In addition, Karlsen et al. (2007) and Beilock et al. (2002) primarily focused on the perception of golfers when utilizing different weighted putter shafts and different sized putter heads. Mallet putters have been rated by golfers as better for aiming due to the size of the head and markings which make aim easier but a study showed blade rather than mallet putters improve aim consistency (Karlsen & Nilsson, 2008b). Interestingly, the middle weighted putter of 420 g was subjectively rated as the preferable weight in comparison to putters of 100 g and 610 g. It may have been perceived as just heavy enough to feel more stable than the lighter putter and less susceptible to the effects of the nerves or environmental factors like wind. (Karlsen & Nilsson, 2007). In conclusion, increasing the weight of the putter appears to improve the feeling of stability from the perspective of the golfer.

Design of the putter and its effect on force and direction control is of particular interest now that an official ruling to uphold USGA and R&A rules has banned the anchored putting stroke. This ruling came into effect January 1, 2016 and seeks to maintain the integrity of the game by requiring a traditional or conventional swing to be used (Johnson, 2013). While long putters may still be used without anchoring to the chest or belly it may be beneficial for golfers to switch to a standard length putter if the same stability can be generated with a standard length putter with the counterbalancing technology. Using longer putters without anchoring is still not utilizing a traditional putting stroke and rules may in the future transition to remove the long putters from the game completely. The counterbalanced putter has been brought onto the market in order to mimic the effect of the long putter on putting performance while using a conventional swing with a conventional length putter. The shaft used in the PING™ counterbalanced putter is similar to a cut down belly putter shaft, slightly thicker in diameter and weighs more than the normal putter shaft. Exact details about the shaft weight are unknown and varies based on the shaft length. Counterbalanced putters add extra weight to the proximal or butt end of the putter to simulate the stability of anchored putters in the hopes that it will produce a smoother stroke. The additional weight is inserted at the top, just under the grip (K. Dynes, personal communication, June 26, 2015). It is not exactly known how this new design will affect performance when utilized by both expert and novice golfers, making the study of the putter design necessary, especially in light of the PGA rule change. If key variables important for increased force and direction control are identified between distances, implement differences, and different expertise level this may also develop the way the skill is instructed.

In conclusion, differences have been identified in conventional putters when head shape and design is manipulated. A larger putter head has been found to worsen aim despite golfers perception of having better aim with a larger putter. Utilizing the anchored putter against the belly or sternum has identified between performance at shorter distances, equivalent performance at medium distances and worse performance at longer distances. Studies which examined putters with differing weight characteristics did not specifically examine whether increased weight of the putter resulted in better performance levels. It is not known how the use of a differently weighted shaft such as that in the counterbalanced putter will affect novice and expert golfers' ability to aim towards a target at varying distances and whether it will be advantageous for performance.

1.4.2 Expertise

Differences between experts and novices have been identified by Delay et al. (1997), Beilock et al. (2002), Schmidt, 2003, Karlsen, Smith, and Nilsson (2007), Karlsen et al. (2008), Karlsen & Nilsson (2008a), Schmidt and Wrisberg (2008), Sim and Kim (2010), Hasegwa et al. (2013) and Kooyman et al. (2013) in variables essential for the control of the force of the golf putt. Face angle, putter head rotation and impact point, which affect the direction of the ball have not been compared between the two groups.

The backswing timing of experts was identified by Delay et al. (1997) as being longer for experts than novices (584 ms vs. 496 ms). Sim and Kim (2010) also identified an increased backswing time in experts and suggested increased backswing time was a significant contributor to better performance. Delay et al. (1997) subsequently identified a longer downswing time in experts than novices (709 ms vs. 563 ms) and Sim and Kim (2010) identified times of 0.423 s and 0.503 s for the downswing in novices and experts, when breaking the downswing into the fore swing and the follow through. Karlsen et al. (2008) identified an optimal downswing time of 325 ms in experts and proposed that training target times of 270-370 ms. Karlsen et al. defined the downswing similar to the fore swing rather than combining the fore swing and follow through (2008).

Delay et al. (1997) found experts start the backswing closer to the ball than novices (6 mm vs. 20 mm), and no other differences between experts and novices in terms of the backswing amplitude. Sim and Kim (2010) also identified control of the backswing amplitude to be a contributor to success in expert golfers in comparison to novices. Sim and Kim (2010) identified differences between novices and experts with backswing amplitudes of 0.307 m and 0.205 m, respectively. Hasegwa et al. (2013) identified similar results when putts were taken from 1.25 m, 1.5 m, and 1.75 m by expert golfers with handicaps less than 10. Delay and colleagues (1997) found the downswing amplitude was significantly larger in experts compared to novices (671 mm vs. 520 mm) when 10 experts (handicap less than 5) and 10 novices (no experience) were tested. It was found that downswing amplitudes were affected by increasing distance in novices more than experts. Experts also contacted the ball in the first third of the downswing while novices contacted exactly half way through.

Kooyman et al. (2013) tested five experienced and four inexperienced participants who completed two sets of 15 putts from 1.5 m, 3 m, and 6 m and found tempo and success for experts and novices across all three distances was 2.14:1 and 2.41:1, and 66.7% and 45.3%. According to the schema theory, relative timing of a movement is considered an invariant feature of a motor program and should not change regardless of the distance or force parameters (Schmidt, 2003; Schmidt and Wrisberg, 2008). Therefore, Kooyman et al. (2013), shows different relative timing may occur due to a difference in experience and a less refined schema for the task, which will be reflected by different levels of performance.

Delay and colleagues (1997) identified a value of 1.78 for experts, with a higher SLR generally being associated with greater expertise. An SLR of 1.96 was identified in the experts in the study completed by Karlsen et al. (2008) but they did not make a comparison to novices in their study. There is also no literature in regards to how the variability in this measure may change with various distances, putter types, or between expertise levels.

Karlsen, Smith, and Nilsson (2007) found in 71 elite golfers (handicap less than 10) putting from 4 meters that the club head velocity was 1.4 ± 0.25 m/s. Sim and Kim (2010) also identified a lower contact velocity and increased success in experts. While focusing on contact velocity, Sim and Kim (2010) also examined average velocities in the different phases of movement. It was also found that the contact velocity generated by novices is more variable with increasing distance in comparison to experts and that novices had a larger contact velocity than experts (Delay et al., 1997).

While examining face angle changes, Sim and Kim (2010) attributed increased success of experts to their tendency to hit the ball on the upward part of the swing after testing five experts with single digit handicaps and five novices with no experience at 1.7 m, 3.25 m, and 6 m with two different weighted putters. Karlsen et al. (2008) utilized both face angle and putter path or putter head rotation to examine the putter's movement along the Y-axis and the rotation of the head during the shot. Their study identified a face angle change of 0.6±0.22° open in expert players and an optimal face angle of 1.6° open, suggesting training should focus on attaining an optimal range of 1° open to 4° closed. Overall, a 10% improvement in face angle consistency. A putter path deviation of 1.04±0.38° in elite golfers was also identified. Optimally, putter head rotation should not change at all and training should target a range of less than ±1.5°**.** A subsequent study by Karlsen and Nilsson (2008a) found regardless of aiming to a far target or a close target, expert golfers aim about 1.0±1.4 degrees left or open across various distances (Karlsen & Nilsson, 2008a). Qualitatively, for both the downswing and backswing it was found that the path of the putter was planar and relatively invariable for experts in comparison to novices (Delay et al., 1997). Karlsen et al. (2008) found a change in impact point of 2.72±0.78 mm in experts. Sim and Kim (2010) did not show many significant differences between novices and experts for impact point.

Experienced golfers have been found to be more successful than novices regardless of putter type (Beilock et al., 2002). Beilock and colleagues (2002) used a dual task condition causing all groups except the expert-regular putter group to decline in performance level. This suggests experts are good enough that they can execute the task with a familiar putter while distracted. Expert performance did not decline between the regular and 'funny' putter, which had a regular putter head and s-shaped shaft, without distraction, illustrating experts are good enough to adapt their technique and make their efforts successful when given the chance to focus. In contrast, the expert group declined in performance when required to use the 'funny' putter and attend to the distraction. Novices did not performance significantly different with either putter (Beilock et al., 2002).

In conclusion, expert golfers have increased backswing and downswing amplitudes, backswing and downswing timing, a larger stroke length ratio, lower contact velocities and decreased variability in face angle and putter head rotation, in comparison to novice golfers.

1.4.3 Distance

Previous research completed by Delay et al. (1997), Lai, Hetchl, Wei, Ball and McLaughlin (2001), Schmidt (2003), Schmidt and Wrisberg (2008), Karlsen et al. (2008), Sim and Kim (2010), Hasegawa et al. (2013) indicated a number of changes occurring in variables responsible for force control and performance changes as distance to the target was increased.

Delay et al. (1997) identified a significant increase in backswing timing (457 ms, 527 ms, 563 ms, and 593 ms) at distances of 1 m, 2 m, 3 m, and 4 m. Delay et al. also found that the time was significantly shorter at 1 m but there was no statistical difference between the downswing time at 2 m, 3 m, or 4 m (596 ms, 649 ms, 649 ms, 651 ms). It was determined that the ratio between the backswing and the downswing time, or tempo, should be 2:1 at any given distance (Lai, Hetchl, Wei, Ball and McLaughlin, 2001). According to the schema theory, the relative timing of a movement is considered an invariant feature of a motor program and should not change regardless of the distance or force parameters (Schmidt, 2003; Schmidt and Wrisberg, 2008).

Backswing amplitude is considered to be the most important variable for applying force to the ball at varying distances based on the findings of Delay et al. (1997) because it subsequently controls the amplitude of the fore swing portion of the downswing that will generate the force needed to ensure the ball reaches its target. Backswing amplitude was found to increase with increasing distance (138 mm, 200 mm, 250 mm, and 297 mm from 1 m, 2 m, 3 m, and 4 m). An increase in downswing amplitude was also identified as distance increased, regardless of expertise. The amplitudes were found to be 354 mm, 541 mm, 677 mm, and 810 mm for putts at 1 m, 2 m, 3 m, and 4 m, respectively. (Delay et al., 1997). When examining the stroke length ratio, it was determined that the 2:1 ratio was generally maintained at every distance despite both the follow-through and fore swing amplitude increasing with increasing distance (Delay et al., 1997). There is also no literature in regards to how the variability in this measure may change with various distances, putter types, or between expertise levels.

Delay et al. (1997) identified increasing contact velocity with increasing distance and this relationship was also identified in a later study (Hasegawa et al., 2013). The variability differences were not overly emphasized by the Delay study (1997) and it is also not known how contact velocity may vary with changing distance and with different putter types.

Sim and Kim (2010) examined both the average change in impact point and used it as a measure of aim consistency. The results of this study showed impact point changed the most between the short and middle distances, with the far distance being no different than the middle distance. Previous research has identified changing performance with increasing distance (Delay et al., 1997; Beilock et al., 2002; Karlsen & Nilsson, 2007; Karlsen et al., 2008; Sim and Kim, 2010, Hasegwa et al., 2013; Kooyman et al., 2013), even at the level of the Professional Golf Association (PGA) players as shown in **Figure 1.3**. Subsequently, it can be concluded that, regardless of putter type or expertise level, performance should decrease as distance increases.

While the above changes have been identified with changing distance there has been very little research completed on how face angle or putter head rotation may be affected by target distance and very little is known about the variability of all the force and direction variables.

In conclusion, golf putting is an example of a closed, discrete motor skill in which expertise may develop with practice. It has been shown, in order to control the putt and increase force necessary for success at further distances, amplitudes of different phases are adjusted while keeping timing constant, regardless of expertise level. Increasing distance also affected the ability of novices to produce the required force and made their putting more variable (Delay et al., 1997). Expert-novice differences have been identified in the following quantitative variables in relation to force production: backswing timing, downswing timing, stroke length ratio, contact velocity and acceleration (Delay et al., 1997). Successful putting also requires the direction of the putt be controlled. Components that contribute to direction control include face angle, putter path, and horizontal movement of the putter (Karlsen et al., 2008). These characteristics have been identified in expert golfers but quantitative expert-novice differences specifically in direction control related variables have not yet been conclusively identified in one study. The effects of kinematic variability on performance are not conclusive.

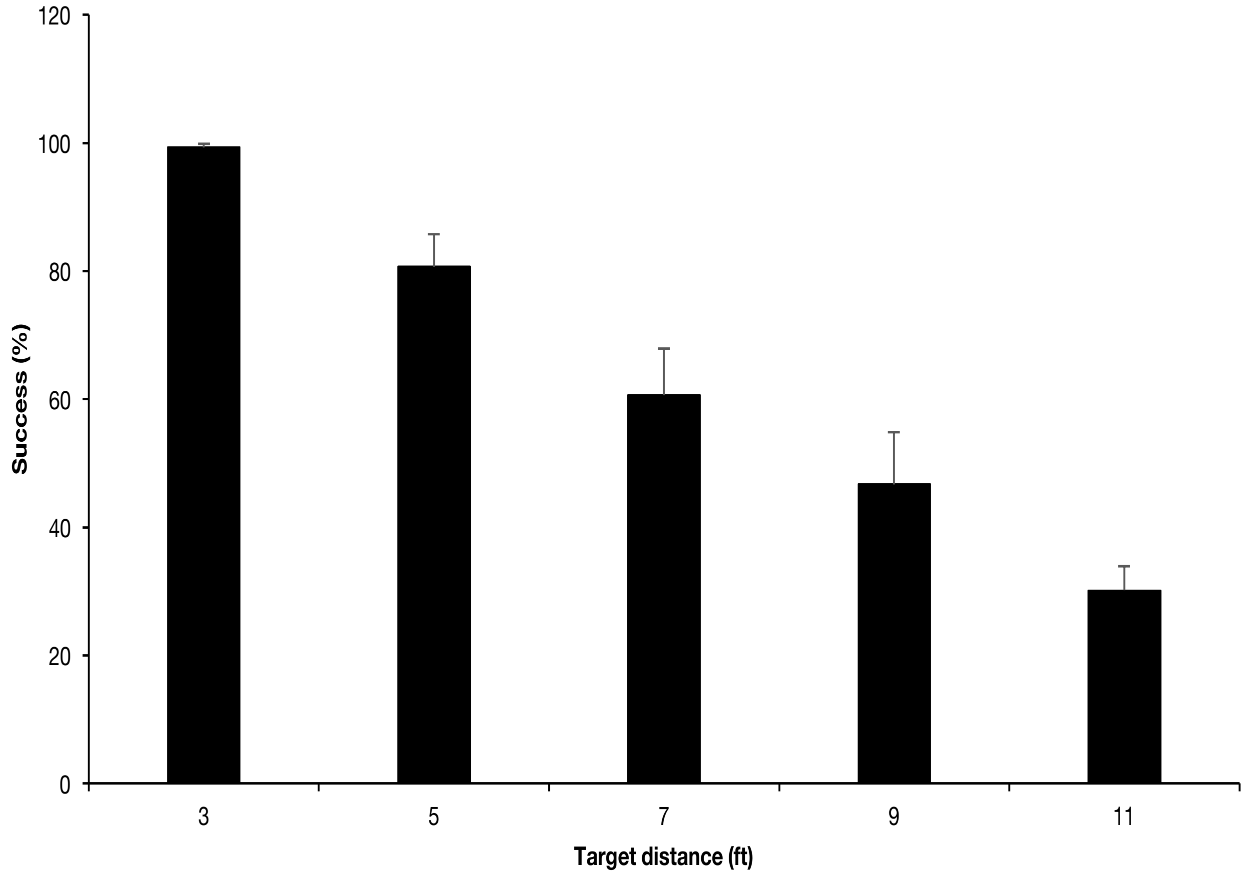

Figure 1.3. Mean percentage of putts made from numerous distances based on amalgamated PGA Tour 2014 stats (PGA Tour, 2014).

1.5 Purpose

This investigation was designed to identify kinematic and performance differences between the counterbalanced and conventional weighted golf putters when utilized by experts and novices while putting to increasing distances.

1.6 Hypotheses

Predictions concerning the changes to be observed in backswing and downswing time, backswing and downswing amplitude, relative timing, stroke length ratio, contact velocity, face angle, putter head rotation, impact point, and performance outcome are based on various findings from a number of previous golf putting studies. While some studies have identified variability differences in variables, it is not known exactly how variability will change with increasing distances, different putter types, and within different expertise levels. Variability should generally increase with increasing distance and be lower in the expert group in comparison to the novice.

1.6.1 Putter

There will be no differences in the backswing time or downswing time between putters (Sim and Kim, 2010). The variability in the timing of both phases will be decreased by the counterbalanced putter in comparison to the conventional. Changing force parameters, with the increased weight in the counterbalanced putter, will not change the relative timing of the phases of movement. There will be no differences in backswing or downswing amplitudes between the conventional and counterbalanced putters (Sim and Kim, 2010) but the variability of both phase amplitudes will be decreased by the counterbalanced putter. The stroke length ratio will not change (Delay et al., 1997; Kooyman et al., 2013) and will be more variable in the conventional putter. Contact velocity will be larger in the conventional putter (Delay et al., 1997; Sim & Kim, 2010). The variability will be lower in the counterbalanced putter compared to the conventional. Face angle, putter head rotation, and impact point will not change between putter types (Karlsen & Nilsson, 2007; Karlsen et al., 2008) and the counterbalanced putter will decrease the variability in all three measures. Constant and variable error in the lateral direction will be increased in the conventional putter, while constant error in the horizontal direction will not vary between putters and the variable error will be decreased by the counterbalanced putter. Binary performance measures should not change for novices between putters and the experts will show increased performance levels with the counterbalanced putter.

1.6.2 Expertise

The backswing and downswing timing will be increased in the experts compared to the novices (Delay et al., 1997). The variability in the timing of both phases will be decreased in the expert group due to increased experience levels. There will be a difference in relative timing of each phase between groups, experts have a longer backswing time, shorter fore swing time and a longer follow through time than novices, regardless of distance and putter type (Delay et al., 1997, Sim & Kim, 2010). Backswing and downswing amplitude will be larger in the expert group (Delay et al., 1997, Sim & Kim, 2010). The variability of the backswing and downswing will be decreased in the expert group (Delay et al., 1997). The stroke length ratio will vary between experts and novices. Experts will have a SLR of 2 while the novices will be closer to a value of 1 (Delay et al., 1997; Kooyman et al., 2013) and novices will be more variable. Contact velocity will be decreased in the expert group compared to the novices (Delay et al., 1997; Sim & Kim, 2010) and less variable in the expert group. Face angle, putter head rotation, and impact point will not be different in the experts and novices (Karlsen, & Nilsson, 2007; Karlsen et al., 2008). Lateral and horizontal constant and variable error will be lower in the experts compared to novices as well as binary performance measures being consistently higher in the expert group regardless of putter type or distance.

1.6.3 Distance

Backswing time will increase with increasing distance (Delay et al., 1997; Sim & Kim, 2010). We predict there will be no significant differences in downswing time of either group with changing distance (Delay et al., 1997) Within-subject variability in the backswing and downswing time will increase with increasing distance as the distance that the golfers will need to cover will increase and therefore become more inconsistent. Relative timing of each phase (backswing, fore swing, and follow through) in comparison to total movement time will not change with increasing distance, according to Schmidt's schema theory (1975), despite demonstrated increases in backswing time with increasing distance (Delay et al., 1997). Backswing and downswing amplitude will increase with increasing distance (Delay et al., 1997; Sim & Kim, 2010). Within-subject variability in backswing and downswing amplitude will increase with increasing distance. The stroke length ratio will not change (Delay et al., 1997; Kooyman et al., 2013) but the standard deviation of the ratio will increase. Contact velocity will increase with increasing distance (Delay et al., 1997; Sim & Kim, 2010) and the variability in contact velocity will also increase. Face angle and putter head rotation will not change with increasing distance (Karlsen, & Nilsson, 2007; Karlsen et al., 2008). Impact point will change with distance (Karlsen, & Nilsson, 2007; Karlsen et al., 2008). Within-subject variability of the face angle, putter head rotation, and impact point in impact point will increase with increasing distance. Constant error in both lateral and horizontal directions will change with increasing distance and variable error in both directions will increase. Binary performance measures will show decreased performance with increasing distance.

1.7 Significance of study

This study examines force and direction control in golf putting. One novel feature is in the testing of the counterbalanced putter which will provide the first comparison of this brand new technology to the conventional putters already on the market. This element will add to previous literature about the effects of changing the design of an implement. Examining differences between novices and experts will give us a better understanding of the learning process which needs to occur in order for novices to become expert putters. Performance being examined at numerous distances will provide more evidence about the force- distance relationship in a discrete motor task. This study will also be looking closely at the effect within-subject variability has on force and direction control.

Chapter 2: Methods

2.1 Environment

A piece of 10 by 12 ft section of EZturf (ez-grass Inc., Leduc, AB) was placed between two ceiling mounted Visualeyez camera units (PTI, Burnaby, BC) (**Figure 2.1**). The speed of the green was obtained by measuring the stimp reading of the turf which was measured as 10.6. The camera units detect the active signal of markers attached to the putters at a sampling rate of 120 Hz. The coordinate system was set up as shown in **Figure 2.1** with the origin established at the balls starting position. The positive Z-axis points into the floor, while the positive Y-axis points directly back opposite of the direction of ball travel and the positive X-axis points in the direction the participant is facing. An 11-foot long string was attached to the end of the surface, on the left end of the black line shown in **Figure 2.1**, and marked at 3, 5, 7, 9, and 11 ft from the balls starting position. The string was used so there were no permanent marks left on the putting surface and other distances would not be visible during the data collection process. The target used was a white circle with a diameter of 4.25 inches cut out of white felt.

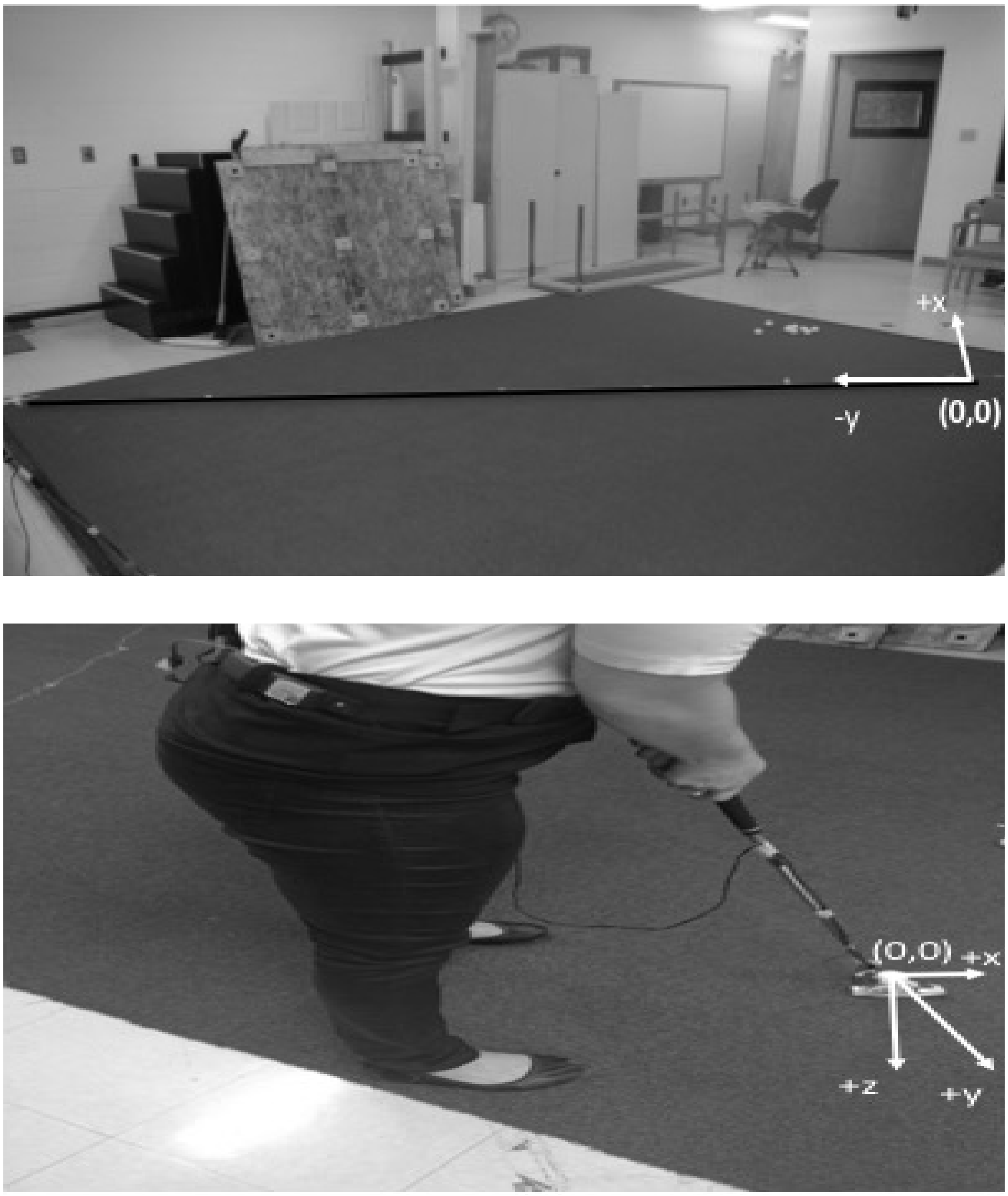

Figure 2.1. The environment was set up such that the flooring surface was along the XY plane and all putts were made along the negative Y axis while the +Z axis pointed into the floor. All balls started at the origin (0,0). Cameras were positioned on the ceiling on either corner of the surface (top image). Wired markers attached to the putter are plugged into a device that is plugged into a battery. These devices are worn on a belt and clipped around the participant's waist (bottom image).

2.2 Participants

Purposive sampling and word of mouth were used to recruit participants from the wider university community and the City of Edmonton. Study information was sent to the University of Alberta golf team and participants from a previous study. Posters were placed throughout the university campus. Word of mouth recruitment was encouraged amongst potential participants.

Twenty participants (5 female) were recruited between the ages of 19 – 65 years with an average age of 33.1 ±14.6 years. All participants were right hand dominant with normal or corrected to normal vision and no known neurological problems. Participants were excluded if they were outside the desired age range, were left handed or golfed with left handed clubs, or had unfixed vision problems or neurological problems.

Participants provided informed consent (**Appendix B**) and were placed in one of two groups based on golf expertise level provided in an inclusion questionnaire (**Appendix C).** Participants were placed in the expert group if they had a known golf handicap of 15 or less, and had 10+ years of playing experience. Beginners were defined as those with no known golf handicap and limited to no experience.

The novice group was comprised of 10 individuals (5 females) with an average age of 27.2±7.0 years, and a range of 0-5 years of golf experience consisting of a total of 0-4 rounds per year. The expert group consisted of 10 individuals (all male) with an average age of 38.9±18.1 years, a range of 10-43 years of experience consisting of 6-100 rounds per year. The experts had an average self-reported handicap of 9.7±3.9. Participant characteristics and experience levels are shown in detail in (**Appendix D).**

2.3 Implements

Participants were provided with both clubs being tested. Three infrared markers were attached to both a conventional and counterbalanced putter. Two of the markers were placed on the club head, one at the furthest point from the shaft and one placed laterally away from the club face. The third marker was placed on the club shaft 10 inches above the club head on the conventional putter and 17 inches on the counterbalanced putter to account for the increased weight of the shaft and its effect on the center of gravity of the putter. The exact placement of markers is shown in **Figure 2.2**. The label indicating the counterbalancing feature of the counterbalanced putter was covered with tape and the same location was taped on the conventional putter to ensure they were visually similar. Putters were referred to as putter 1 and putter 2 during testing but were not labeled with these numbers. The markers were plugged into a battery pack and a belt holding the battery pack was worn around the participants' waist (**Figure 2.1**). The cords attached to the markers were secured to the putter with masking tape to minimize possible interference with putting technique. The implement set up has been proven to be effective for tracking of club movement in previous studies (Hladky, Roshko, and Maraj, 2014). Characteristics of putters provided by experimenters are shown in **Table 2.1.** All participants used balls provided in the laboratory (Titleist Pro V1, Acushnet Co., Fairhaven, MA, USA)

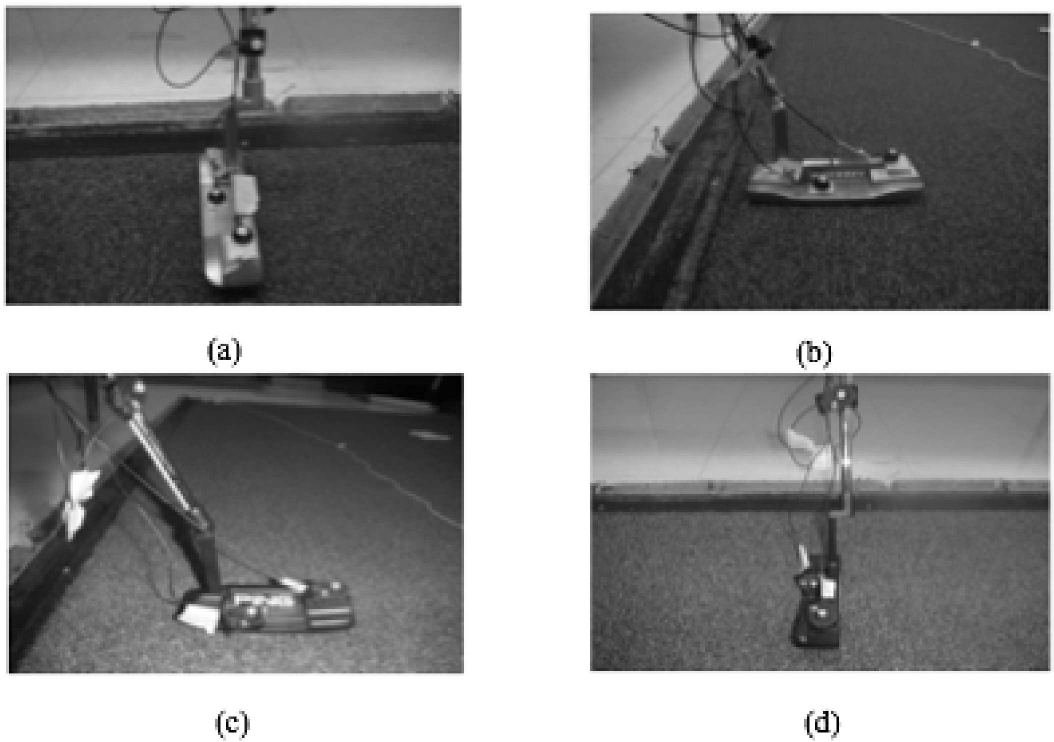

Figure 2.2. Putters and markers. (a) and (b) show the conventional Odyssey™ putter and (c) and (d) show the counterbalanced PING™ putter. The placement of Visualeyez markers are also shown.

Table 2.1. Characteristics of Odyssey™ and PING™ putters

Putter	Odyssey™ White Hot Pro	PING™ Cadence True Roll
Type	Conventional blade	Counterbalanced blade
Hand	Right	Right
Offset	Full shaft	Heel
Length (in)	35	36
Head weight (g)	343	400
Shaft weight (g)	*	120
Lie angle (°)	70	4

Note: Information for Odyssey™ putter from Callaway Golf (2013) and PING™ information from PING Inc. (2012). Shaft weight for PING™ was attained through personal communication (K. Dynes, personal communication, June 26, 2015). (*)Shaft weight for Odyssey™ putter was not available.

2.4 Task and Instructions

All participants received approximately 4 min of free practice during which they were told to take shots from various distances. The practice period typically resulted in 9-18 practice shots being taken with each putter before testing began. All participants were told the 5 most accurate participants in their group would be put into a random draw for a prize of $60.00 value. The novice group winner received a gift card for Starbucks and the expert group winner received a box of Titleist Pro V1 golf balls. This incentive was provided to generate competition and encourage participants to stay motivated during testing. Participants were not told the difference between the putters until the testing session was completed. In the information letter, participants were informed the aim of the putting task was to get the ball to come to a rest on or against a target **(Appendix E),** this was reiterated verbally and participants were assured any ball which contacted or went over the target would be considered for the scoring towards the draw for the incentive.

At the beginning of each trial the participant was asked to grip the putter and stand with the putter head flush against the ball at the starting position. The experimenter began data collection and indicated the beginning of the trial with a verbal "GO" signal; the participant executed the putt, and data collection for the trial was ended as soon as the experimenter witnessed the end of the follow-through phase. The final location of ball was captured with a digital camera for post-hoc analysis, the ball was retrieved, the target was then moved to the next distance and the participant readied themselves and the ball for the next trial. Order of putter presentation (conventional and counterbalanced) was counterbalanced or alternated between participants to eliminate testing order effects and the distance order was randomized with an online randomizer (https://www.randomizer.org) such that no distance was repeated more than twice in succession. Presentation order differed between putter for each participant but an expert performed in the exact same order as one novice.

Participants took a total of 15 putts at each of the five distances and an optional 1 min break was provided after every 15 trials. This was repeated with the second putter after a mandatory 5-minute break for a total of 150 putts being taken during the session. For an example of the randomized trial order and break schedule during testing, refer to **Appendix F**.

2.5 Data Collection and Reduction

Raw putter kinematics were collected at 120 Hz and generated using VZsoft and VZAnalayzer (PTI, Burnaby, BC) software. This data was transposed using a custom designed Matlab program (The Mathworks Inc., 2008) as well as other data processors. The Matlab program was designed so that each trial was treated separately. For each trial, ball address (initial putter position on the y-axis) was selected by hand and the program then identified the remaining portions of the swing: the top of the backswing (maximal putter position on the y-axis), ball contact (return to initial putter position on the y-axis), and the end of the downswing (minimal putter position on the y-axis) was identified.

These positions were then used by the custom Matlab program to calculate the amplitudes and timing of each phase, the average velocity of the putter when making contact with the ball, and the changes in face angle, putter head rotation, and impact point. Microsoft Excel was subsequently used to calculate downswing timing and amplitude as well as absolute contact velocity, relative timing of phases and the stroke length ratio (SLR) or relative follow-through amplitude. Average kinematic values were calculated with the means from each subject and the standard deviations from each subject represent the within-subject variability measures. Outliers were removed if they were more than 2.5 standard deviations from the mean. Kinematic and performance variables were calculated based on the following:

Backswing time (ms)- time from beginning of movement to putter reaching its maximal position on the positive Y-axis.

Downswing time (ms)- time from maximal position on the positive Y-axis to the maximal position on the negative Y-axis

Relative timing (%)- the amount of time spent in the backswing, fore swing, and follow through relative to the duration of the entire putt.

Backswing amplitude (mm)- distance travelled by putter from beginning of movement to putter reaching its maximal position on the positive Y-axis.

Downswing amplitude (mm)- distance traveled from maximal position on the positive Y- axis to the maximal position on the negative Y-axis

Stroke length ratio- follow through amplitude divided by the amplitude of the downswing and the follow through amplitude combined

Contact velocity (cm/s)- velocity of the club head when the ball is contacted.

Face Angle (°)- difference between the rotational position of the putter about the X-axis at the beginning of movement and the rotational position about the X-axis at ball contact.

Putter head rotation (°)- difference between the rotational position of the putter about the Z-axis at beginning of movement and the rotational position about the Z-axis at ball contact.

Impact point (mm)- measurement of the lateral movement of the putter and is the difference in putter position on the X-axis from beginning of movement to ball contact.

Performance outcome- quantified by measuring the balls distance from the hole in both directions with the use of digital photographs and Kinovea open source software (Version 0.8.15). Using this program, the target was designated at 4.25 inches in diameter allowing for the distance to the ball in the x, or horizontal, and y, or lateral, directions relative to the centre of the target to be measured. The horizontal measurement was made perpendicular to the direction of ball travel and lateral measurement was made in the direction of ball travel (**Figure 2.3**). A similar technique for error measurement was utilized by Perkins-Ceccato, Passmore, and Lee (2003). The values obtained with Kinovea were rounded to the nearest whole inch. Due to experimental error, if the ball was within 4 inches of the centre of the target it was considered to be "zero" error. These values were then used to calculate performance outcome in terms of constant error (CE) and variable error (VE) in both horizontal and lateral directions, using Excel. Constant and variable error was calculated utilizing the following formula derived from Schmidt and Lee (2005, p. 25-26):

$$CE = \sum \frac{(x_i)}{n}$$

$$VE = \sqrt{\sum \frac{(x_i - CE)^2}{n}}$$

Where:

X_i= score on trial *i*

n= number of trials

The coordinates were also used to determine performance using a binary system with one point assigned if the ball crossed the target, meaning it would have dropped into a regulation hole, zero points are assigned to a trial if the ball did not cross the target.

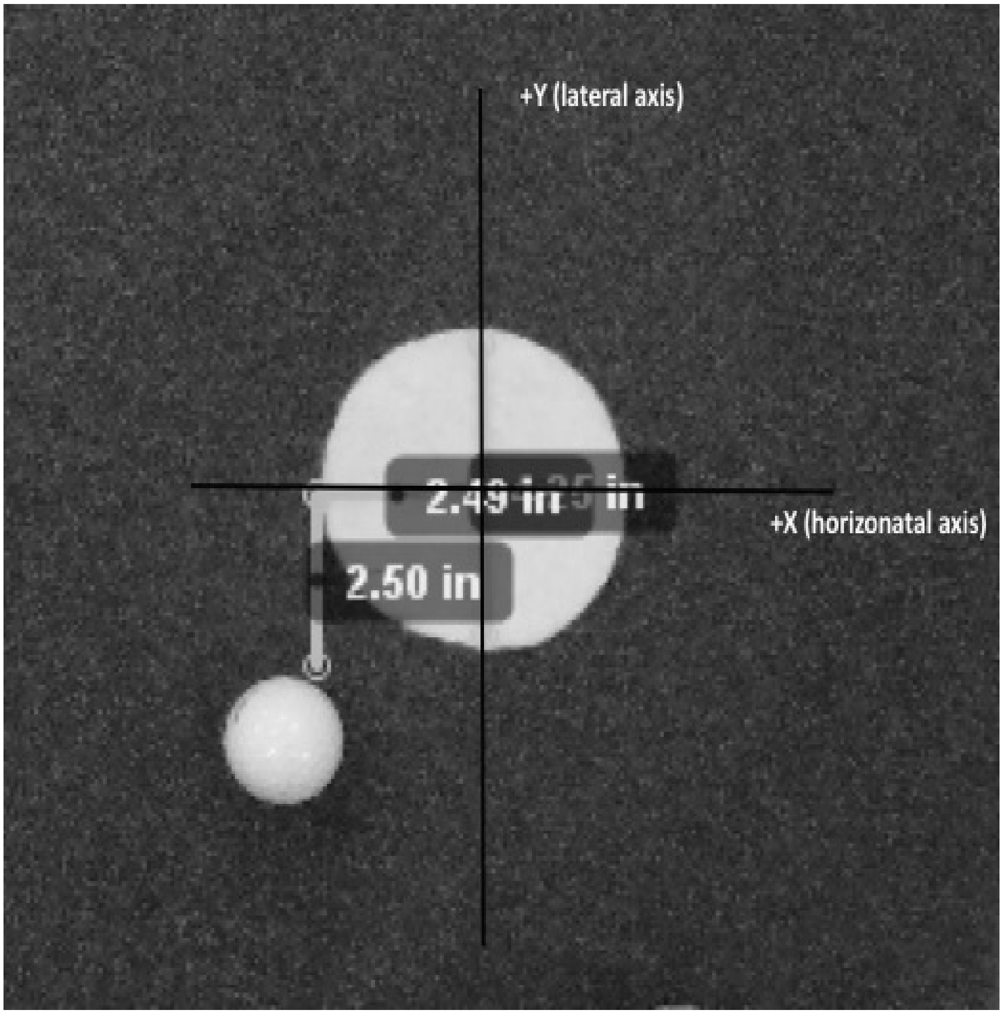

Figure 2.3. Kinovea open-source software was utilized to determine the lateral and horizontal distance of the ball from the centre of the target. The centre of the target was (0,0) and the lateral (Y) and horizontal (X) axis are shown.

2.6 Statistical Analysis

The means and standard deviations of backswing timing, downswing timing, backswing amplitude, downswing amplitude, face angle, putter head rotation, impact point and constant and variable error in X and Y were analyzed with a 2 group (expert/novice) by 2 putter (conventional/counterbalanced) by 5 distance (3, 5, 7, 9, and 11 ft) MANOVA with repeated measures on putter and distance with an alpha level of 0.05 for the mean kinematic variables and corresponding variability measures and 0.05 for the horizontal and lateral constant and variable error. Any significant main effects identified with the MANOVA was followed by individual ANOVA tests. All possible pairwise comparisons were completed on distance effects with a bonferroni correction for multiple comparisons. Effect sizes were reported as partial eta squared (n^2) values. The relative timing of the backswing, fore swing, and follow through was calculated at each distance and for each putter and expertise group. All statistical analyses were completed with SPSS. In addition, relative timing of the backswing, fore swing, and follow through was calculated for the best and worst performing experts and novices, determined by binary performance scores. The putter trajectory along the Y-axis was graphed for the worst performing novice and best performing expert at 3 ft with the conventional and counterbalanced putters.

Chapter 3: Results

The variables responsible for force and direction control and the changes which occur with increasing distance and different putters in both expert and novice golfers will be presented. Performance outcome will also be presented. All descriptive kinematic and performance data can be found in **Appendix G.**

Multivariate testing showed main effects for putter type ($F(9,10) = 5.97$, $p = 0.01$, $n^2=0.84$), distance ($F(36,268) = 4.16$, $p=0.00$, $n^2=0.36$), and group and distance ($F(36,268) = 1.74$, $p=0.01$, $n^2=0.19$) for the average kinematic measures. The within-subject variability measures showed significant main effects for group ($F(9,10) = 9.81$, $p=0.00$, $n^2= 0.90$), putter ($F(9,10) = 15.8$, $p = 0.00$, $n^2=0.93$) and distance ($F(36, 268) = 1.97$, $p=0.00$, $n^2= 0.21$) but no significant interactions. Multivariate testing showed a main effect for expertise level ($F(4,15) = 8.84$, $p=0.00$, $n^2= 0.70$) and distance ($F(16,3) = 18.08$, $p=0.02$, $n^2=0.99$) and expertise level and distance ($F(16,3) = 68.45$, $p=0.00$, $n^2= 1.00$).

Constant and variable error of the performance outcome was separately calculated in the X and Y directions. The Y or lateral direction error is indicative of performance in terms of control of the force of the putt. Error in the X or horizontal direction is indicative of performance in terms of the control of the direction of the putt. Constant error is a measure of accuracy and variable error is a measure of consistency (Schmidt & Lee, 2005). Binary performance measures were compared and shown in **Figure 3.1** and the putter trajectories of a sample of novices and experts with the conventional and counterbalanced putters is shown in **Figure 3.2**.

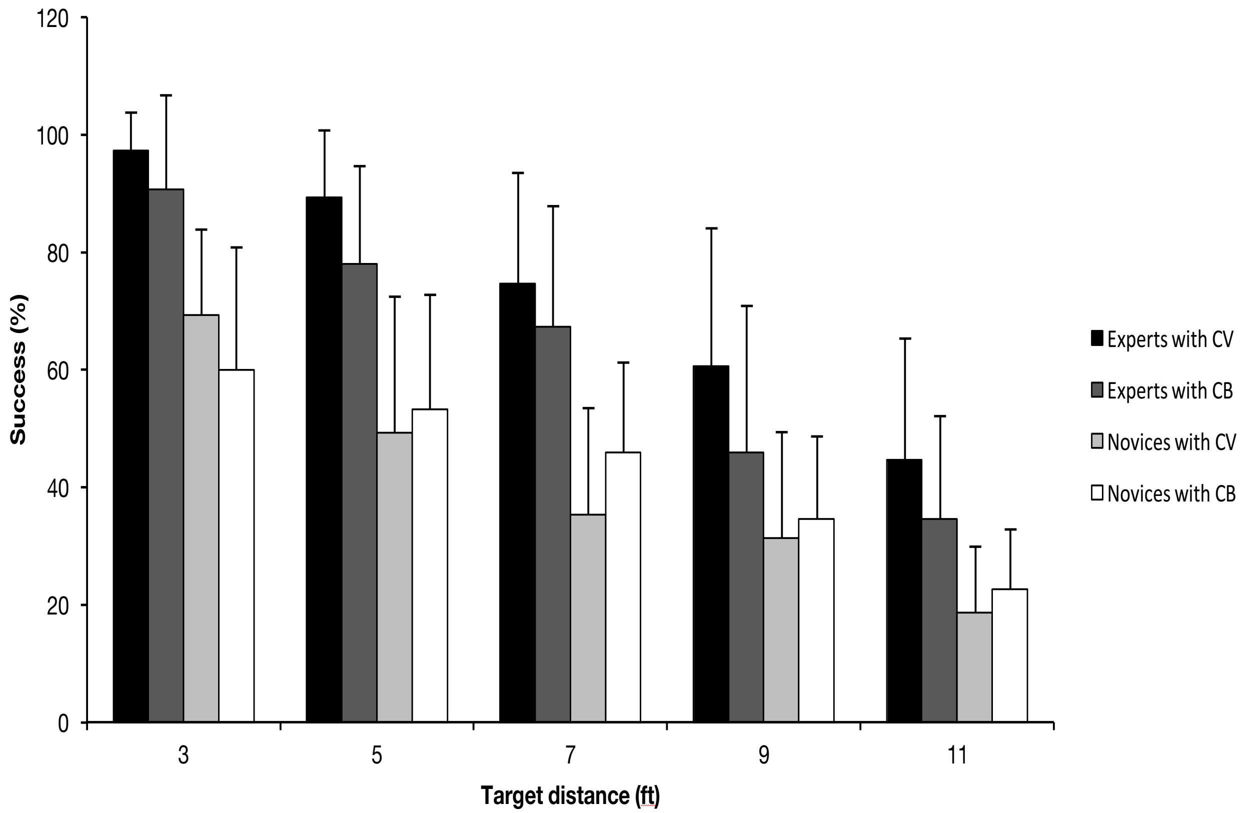

Figure 3.1. Binary performance data for experts and novices with the conventional (CV) and counterbalanced (CB) putter at 3, 5, 7, 9, and 11 ft.

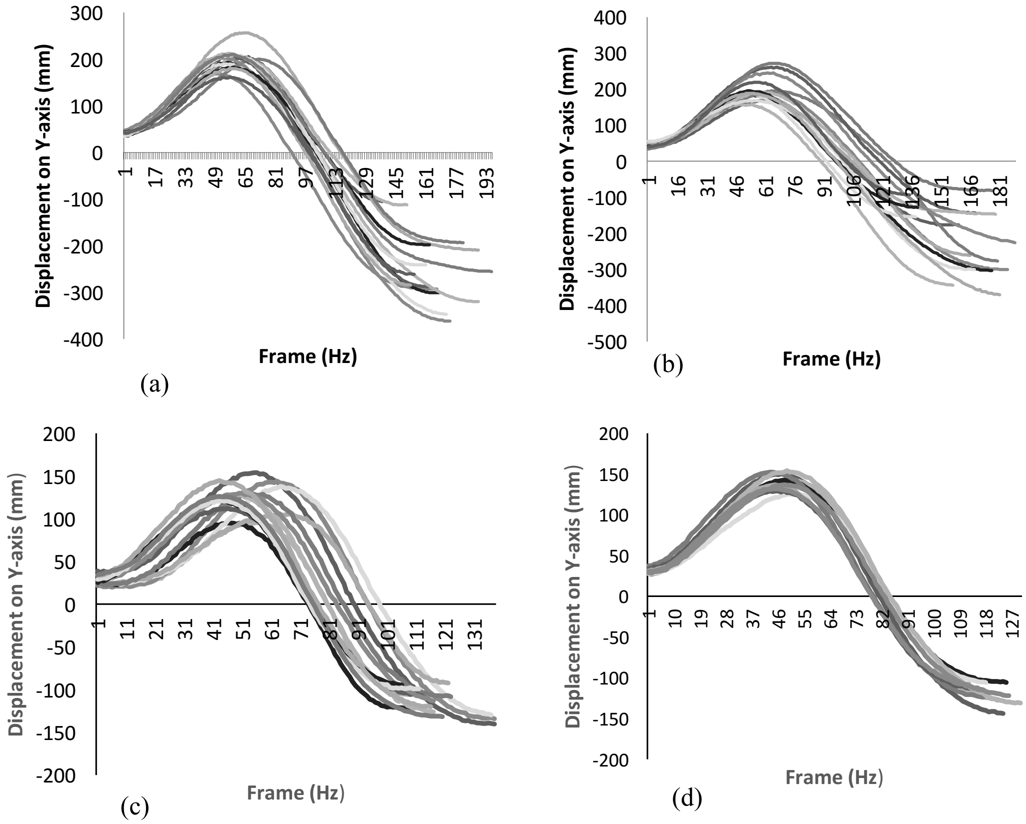

Figure 3.2. Trajectory of **(A)** the worst performing novice using the conventional putter (N=15) **(B)** the worst performing novice using the counterbalanced putter (N=15) **(C)** the best performing expert using the conventional putter (N=15) **(D)** the best performing expert using the counterbalanced putter (N=10).

3.1 Putter type

There were no statistical differences between the conventional and counterbalanced putter when lateral and horizontal constant and variable error was examined. The binary performance measures (**Figure 3.1**) show performance was slightly increased in the novices group and slightly decreased in the expert group using the counterbalanced putter in comparison to the conventional. Despite the lack of a difference in the error measures, main effects for putter were identified in force and direction kinematic variables.

In terms of force-related variables, there were significant differences between the putters for the average backswing timing, average contact velocity and contact velocity variability. The conventional and counterbalanced putters had backswing times of 557±24 ms and 583±31 ms ($p = 0.02$, $n^2 = 0.28$) (**Figure 3.3A**). There were no relative timing differences found between the conventional and counterbalanced putters **(Table 3.1**). The contact velocity was 4.43±0.17 cm/s and 3.20±0.17 cm/s in the conventional and counterbalanced putters ($p=0.00$, $n^2=0.59$) and conventional putter had a more variable contact velocity (3.46 vs. 2.38 cm/s) ($p=0.00$, $n^2=0.44$) (**Figure 3.3B and 3.3C**).

The conventional and counterbalanced putters had average face angles of -0.72±1.06° and -0.41±0.82° ($p=0.02$, $n^2=0.26$), and an average impact point change of -0.1 ±0.9 mm and -0.8±1.0 mm ($p=0.045$, $n^2 = 0.21$) (**Figure 3.4A and 3.4B**). The face angle variability was found to be 1.71±0.05° and 0.97±0.05° for the conventional and counterbalanced putters (**Figure 3.4C)** ($p=0.00$, $n^2=0.86$). Similarly, the counterbalanced putter had a significantly smaller amount of head rotation variability in comparison to the conventional (3.19 ± 0.11° vs. 2.24 ± 0.11°) ($p=0.00$, $n^2= 0.86$) **(Figure 3.4D)**.

Table 3.1. The relative timing (%) of the backswing (BS), fore swing (FS) and follow through (FT) phases of the golf putt of the (1) the worst performing novice (2) the best performing novice (3) the worst performing expert and (4) the best performing expert with a conventional (CV) and counterbalanced putter (CB).

	Participant	1	2	3	4
Putter type	Phase				
CV	BS	36	42	44	43
	FS	21	27	29	22
	FT	43	31	27	35
CB	BS	35	42	46	39
	FS	23	25	29	23
	FT	42	33	25	38

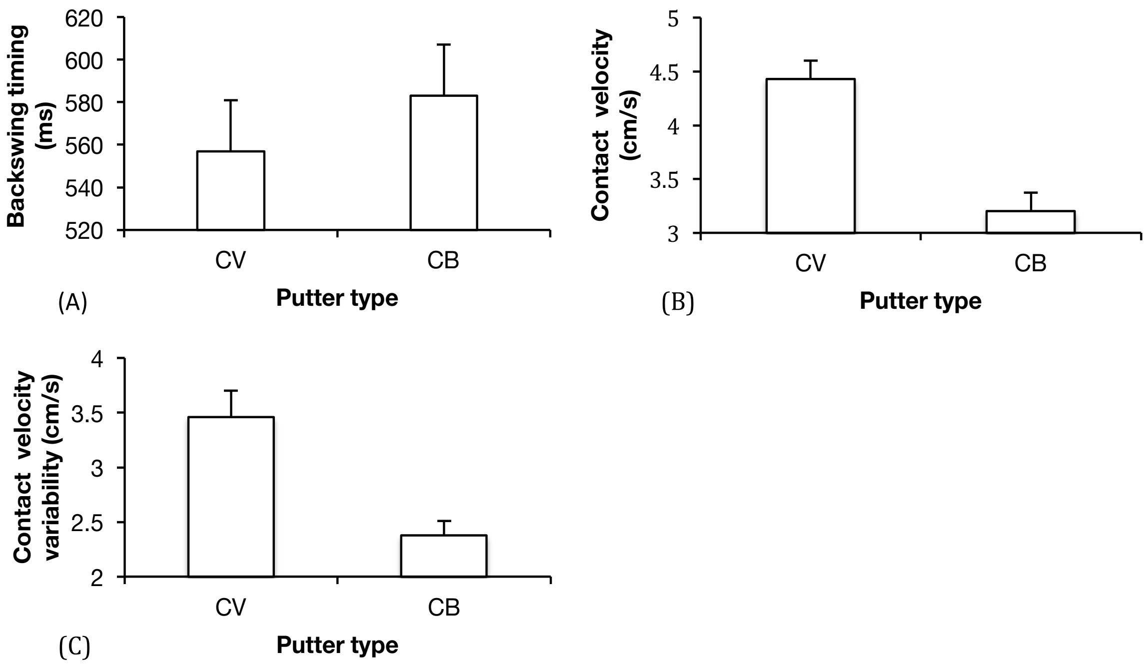

Figure 3.3. **(A)** Backswing timing ($p = 0.01$, $n^2 = 0.28$), **(B)** contact velocity ($p=0.00$, $n^2=0.59$), and **(C)** contact velocity variability ($p=0.00$, $n^2=0.44$) was significantly different between the counterbalanced (CB) and conventional putter (CV). Bars indicate standard error.

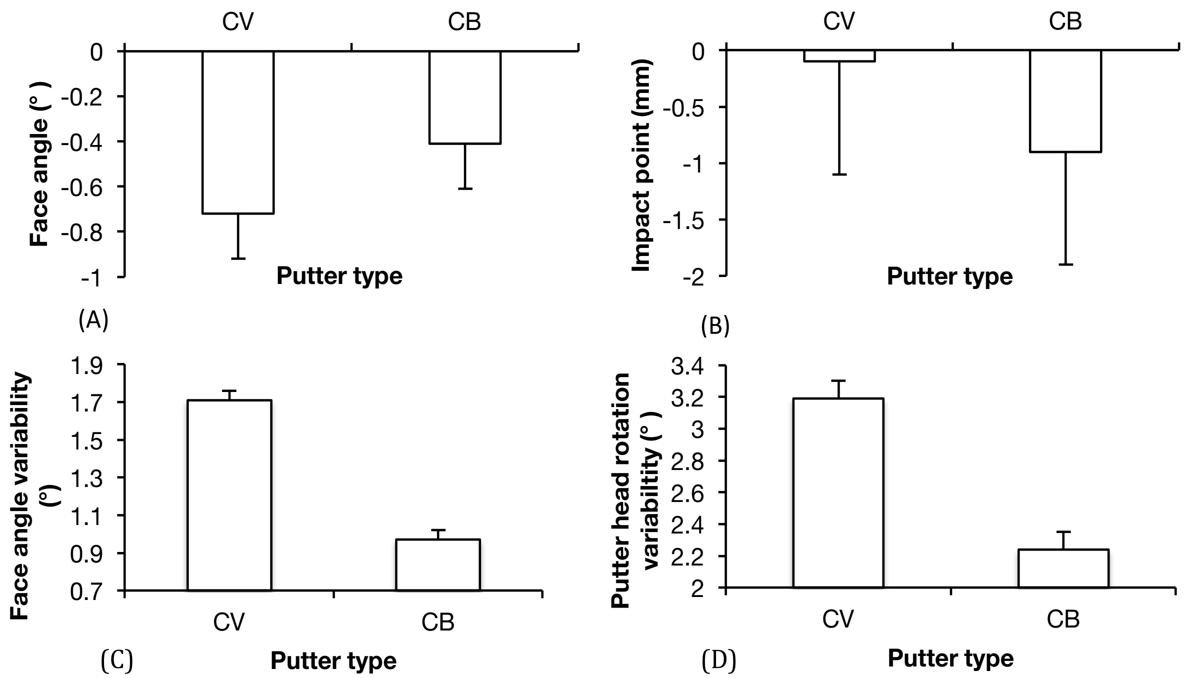

Figure 3.4. (A) Face angle (p=0.02, n^2=0.26), **(B)** impact point (p=0.045, n^2 = 0.21), **(C)** face angle variability (p=0.000, n^2=0.855), and **(D)** putter head rotation variability (p=0.000, n^2= 0.857) were significantly different between the conventional (CV) and counterbalanced (CB) putters with significant main effects for putter type. Bars indicate standard error.

3.2 Expertise level

While not statistically examined the differences between the overall or binary performance in experts is higher than that of novices. But the binary performance measure is qualitatively lower for the counterbalanced putter in experts compared to conventional and the counterbalanced putter shows higher performance than the conventional putter in the novice population. The force and direction performance measures showed that experts were more accurate and less variable in the control of the force and direction of the putt. The horizontal constant error for novices and experts was 0.96±0.13 inches and 0.57±0.13 inches **(Figure 3.5A)** ($p=0.04$, $n^2=0.21$). Variable error measures indicate novices are more variable in the horizontal direction in comparison to experts, regardless of distance and putter type, with variable error scores of 3.18±0.27 inches and 1.40±0.27 inches (**Figure 3.5B**), respectively ($p=0.00$, $n^2= 0.73$). The lateral variable error measures showed a significant main effect between expertise and distance ($p=0.01$, $n^2=0.19$), experts had a consistently higher variable error score than experts (**Figure 3.5**).

A significant expertise by distance effect ($p=0.00$, $n^2=0.23$) was identified in the downswing amplitude. The interaction shows downswing amplitude generally increased in novices but this was variable with changing distance (**Figure 3.6A**). A group by distance effect ($p=0.01$, $n^2= 0.16$) was also identified in the stroke length ratio which found experts were closer got closer to an ideal ratio of 2 at further distances, while novices fluctuated around a ratio of 1 **(Figure 3.6B)**. Novices and experts showed a variability of 33±4 mm and 19±4 mm in the backswing amplitude and there was a significant main effect for expertise level ($p=0.03$, $n^2=0.11$) **(Figure 3.6C).** There are no consistent differences between the relative timing of the backswing, fore swing, and follow through when comparing the best and worst performing experts and novices. When averaged, the worst and best performing novices had lower relative timing percentages with the conventional putter in comparison to the experts at any distance. The relative timing of the phases show relative timing is invariant but the exact percentage of time spent in each phase is individual **(Table 3.1 and 3.2)**

A face angle variability of 1.47±0.05° and 1.20±0.05° for novices and experts, respectively, was identified ($p=0.00$, $n^2= 0.45$) (**Figure 3.6D)**. The within-subject variability values for putter head rotation show novices have a significantly larger variability in comparison to experts (3.17±0.14° vs 2.26 ±0.14°) ($p=0.00$, $n^2= 0.54$) (**Figure 3.6E).** The within subject variability in impact point for novices and experts was 7.0±0.4 mm and 3.4±0.4 mm (**Figure 3.6F)** ($p=0.00$, $n^2=0.73$).

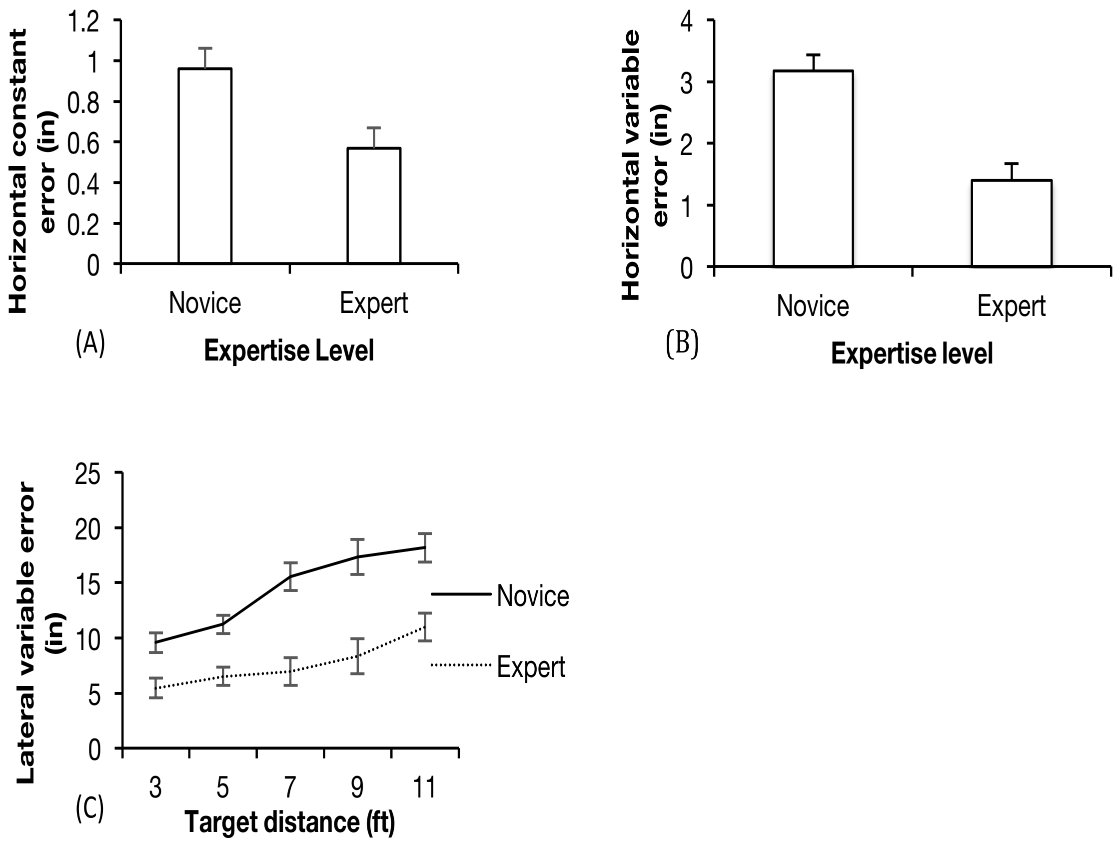

Figure 3.5. Novice golfers (N=10) show increased **(A)** horizontal constant ($p=0.04$, $n^2=0.21$) and **(B)** variable ($p=0.00$, $n^2= 0.73$) error in comparison to expert golfers (N=10). There was a **(C)** group by distance effect in lateral variable error ($p=0.01$, $n^2=0.19$).

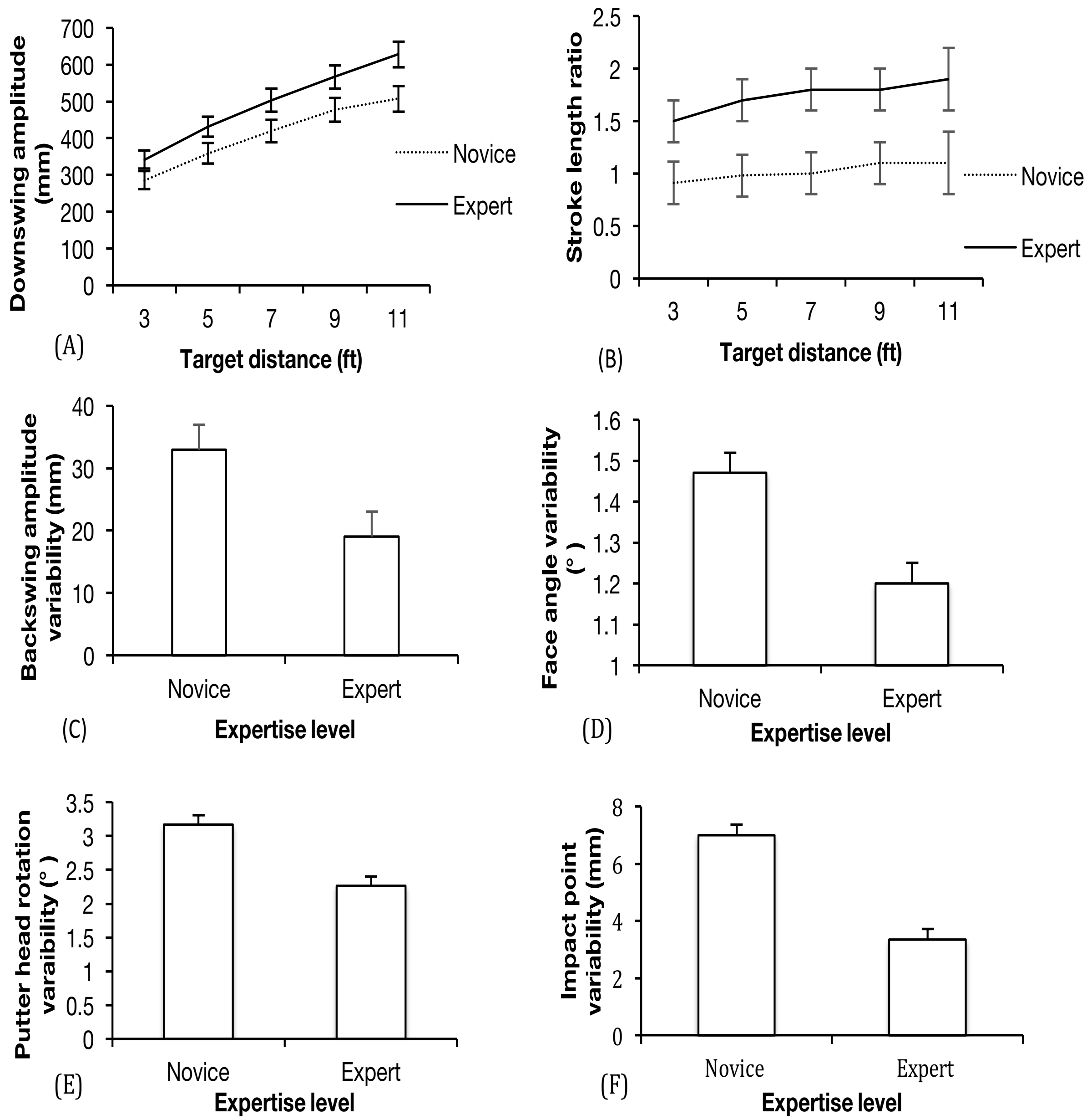

Figure 3.6. There was a group by distance effect identified between novices (N=10) and experts (N=10) in **(A)** downswing amplitude (p=0.00, n^2=0.23) and **(B)** stroke length ratio (p=0.01, n^2= 0.16). Novices also showed increased **(C)** backswing amplitude variability (p=0.03, n^2=0.11), **(D)** face angle variability (p=0.00, n^2= 0.45), **(E)** putter head rotation variability (p=0.00, n^2= 0.54), and **(F)** impact point variability (p=0.00, n^2= 0.73) in comparison to novices. Bars indicate standard error.

Table 3.2. The relative timing (%) of the backswing (BS), fore swing (FS) and follow through (FT) phases of the golf putt of the (1) the worst performing novice (2) the best performing novice (3) the worst performing expert and (4) the best performing expert at 3, 5, 7, 9, and 11 ft.

	Participant	1	2	3	4
Target distance (ft)	Phase				
3	BS	35	43	46	39
	FS	24	27	32	23
	FT	43	30	24	37
5	BS	37	43	46	42
	FS	23	26	30	23
	FT	40	31	26	35
7	BS	35	42	45	41
	FS	22	26	30	23
	FT	43	32	27	36
9	BS	36	42	45	41
	FS	21	25	27	23
	FT	44	34	28	37
11	BS	36	41	46	41
	FS	21	25	28	23
	FT	43	34	27	37

3.3 Distance

Performance differences were identified with changing distance, the lateral constant and variable error both had significant main effects for distance. The lateral constant error, an indicator of force control, at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was 5.87, 5.43, 2.82, 0.75, and -5.39 inches ($p=0.00$, $n^2= 0.64$). (**Figure 3.7A)** Post-hoc analysis shows 3 and 5 ft did not differ from each other ($p=1.00$) but 3 ft did differ from 7, 9, and 11 ft ($p\leq0.04$) and 5 differed from 9 and 11 ft ($p<0.03$), and 7 ft varied significantly from 3 and 11 ft ($p<0.04$), while 9 and 11 ft were also significantly different from each other ($p=0.00$). Horizontal constant error measures at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was 0.00, 0.21, 0.80, 1.55, and 1.27 inches (**Figure 3.7B**) ($p=0.00$, $n^2=0.466$). Post-hoc analysis showing that 3 and 5 ft did not differ from each other ($p=1.00$) while 3 ft was also significantly smaller than 7 ft ($p=0.00$) while 5 ft was not ($p=0.08$). 3 and ft feet were also significantly smaller than 9 and 11 ft ($p<0.01$). The constant error at 9 ft was significantly larger than at 7 ft ($p=0.01$) but not different from 11 ft ($p=1.00$). The lateral variable error at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was 7.53, 8.87, 11.25, 12.86, and 14.58 inches ($p=0.00$, $n^2= 0.61$) **(Figure 3.7C)**. All possible pairwise comparisons show 3 and 5 ft do not differ from each other ($p=0.42$), but both were significantly lower than 7, 9, and 11 ft ($p\leq0.008$), 7 ft was significantly lower than 11 ft ($p=0.01$), and 9 and 11 ft do not differ from each other ($p=0.90$). The horizontal variable error also showed a significant main effect with increasing distance ($p=0.00$, $n^2= 0.76$) and at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was 0.95, 1.61, 2.27, 2.97, and 3.65 inches (**Figure 3.7D**). Post-hoc analysis showed every distance being significantly different from each other ($p<0.05$). Binary performance measures show that performance got increasing worse as the distance increased (**Figure 3.1**)

The backswing times at 3 ft,5 ft, 7 ft, 9 ft, and 11 feet are 541 ms, 561 ms, 577 ms, 581 ms, and 592 ms, respectively ($p=0.00$, $n^2= 0.60$) (**Figure 3.8A)**. Post-hoc analysis showed the backswing timings were all significantly different than each other ($p<0.02$) except 7 and 9 ft did not vary from each other ($p=1.00$). Downswing times were 745 ms, 779 ms, 795 ms, 799 ms, and 798 ms at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft, respectively (**Figure 3.8B)** ($p=0.00$, $n^2=0.48$). Post hoc analysis showed at 5, 7, 9, and 11 ft downswing timing was significantly larger than the time at 3 ft ($p<0.001$) but the four furthest distances did not significantly vary from each other ($p>0.18$). The backswing amplitudes at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft were 156 mm, 186 mm, 213 mm, 233 mm, and 251 mm **(Figure 3.8C)** (p=0.00, n^2= 0.91). Post-hoc tests show significant differences between all distances (p=0.00). Backswing amplitude variability at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was 24 mm, 22 mm, 26 mm, 29 mm, and 30 mm (p=0.00, n^2= 0.24) (**Figure 3.8D).** Post-hoc analysis showed 3 ft and 11 ft were significantly different from each other (p=0.01). A main effect for distance was identified in the downswing amplitude. Downswing amplitude steadily increased distance (314 mm, 395 mm, 461 mm, 522 mm, 568 mm) (p=0.00, n^2=0.96) (**Figure 3.8E)**. Pairwise comparisons show all distances were significantly different from each other (p=0.00). Within-subject variability of the downswing amplitude was 38 mm, 42 mm, 51 mm, 58 mm, and 62 mm at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft (p=0.00, n^2= 0.50) (**Figure 3.8F)** Post-hoc analysis showed 3 and 5 ft were not different from each other (p=0.99) but where significantly smaller than 7, 9, and 11 ft (p<0.02). 11 ft was shown to be significantly larger than 7 ft (p=0.04) and 9 and 11 ft did not differ from each other (p=1.00).

In addition to a group by distance effect (**Figure 3.6B**), there was a main effect for distance in the stroke length ratio (p=0.00, n^2= 0.57), which at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was 1.22, 1.35, 1.40, 1.46, and 1.49, respectively **(Figure 3.9A)**. Post-hoc analysis showed 3 ft significantly smaller than the other distances (p=0.00), 5 ft was significantly lower than 9 and 11 ft (p<0.03) and 7, 9, and 11 ft were not significantly different from each other (p>0.08). A main effect for distance was found in contact velocity (p=0.00, n^2=0.22) and velocities were 3.51 cm/s, 3.43 cm/s, 3.81 cm/s, 4.09 cm/s, and 4.26 cm/s at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft **(Figure 3.9B)**. Pairwise comparisons showed 3 and 5 ft (p=1.00) and 9 and 11 ft (p=1.00) did not differ from each other but 11 ft was significantly larger than 3 and 5 ft (p≤0.02), and 9 ft was significantly larger than 5 ft (p=0.03). The velocity variability at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was 3 cm/s, 3 cm/s, 3 cm/s, 3 cm/s, and 4 cm/s (p=0.01, n^2=0.17) (**Figure 3.9C),** and post-hoc analysis showed a significant difference between the variability at 5 and 9 ft (p=0.04)

Significant main effects for distance were identified in face angle, or rotation about the X-axis Face angle at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was -0.25°, -0.54°, -0.57°, -0.69°, and -0.78°, respectively (p=0.000, n^2=0.334) (**Figure 3.9D)**. Post-hoc analysis shows face angle at 3 ft was significantly smaller than at the other distances (p<0.02) but no other significant differences existed in the face angle change between 5, 7, 9, and 11 ft ($p>0.44$). The impact point at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft was -0.5 mm, -0.9 mm, -0.7 mm, 0.5 mm, and -0.8 mm ($p=0.02$, $n^2=0.15$) **(Figure 3.9E)** and pairwise comparisons show the change was caused by significant differences between the impact point change at 5 ft and 9 ft ($p= 0.01$) and the differences between 9 ft and 11 ft ($p= 0.03$). The variability in impact point at 3 ft, 5 ft, 7 ft, 9 ft, and 11 ft is 4.6 mm, 5.1 mm, 5.3 mm, 5.1 mm, and 5.7 mm, respectively ($p<0.05$, $n^2= 0.13$**)** **(Figure 3.9F)** and post –hoc analysis shows this was caused by a significant difference between the variability at 3 and 11 ft ($p<0.01$).

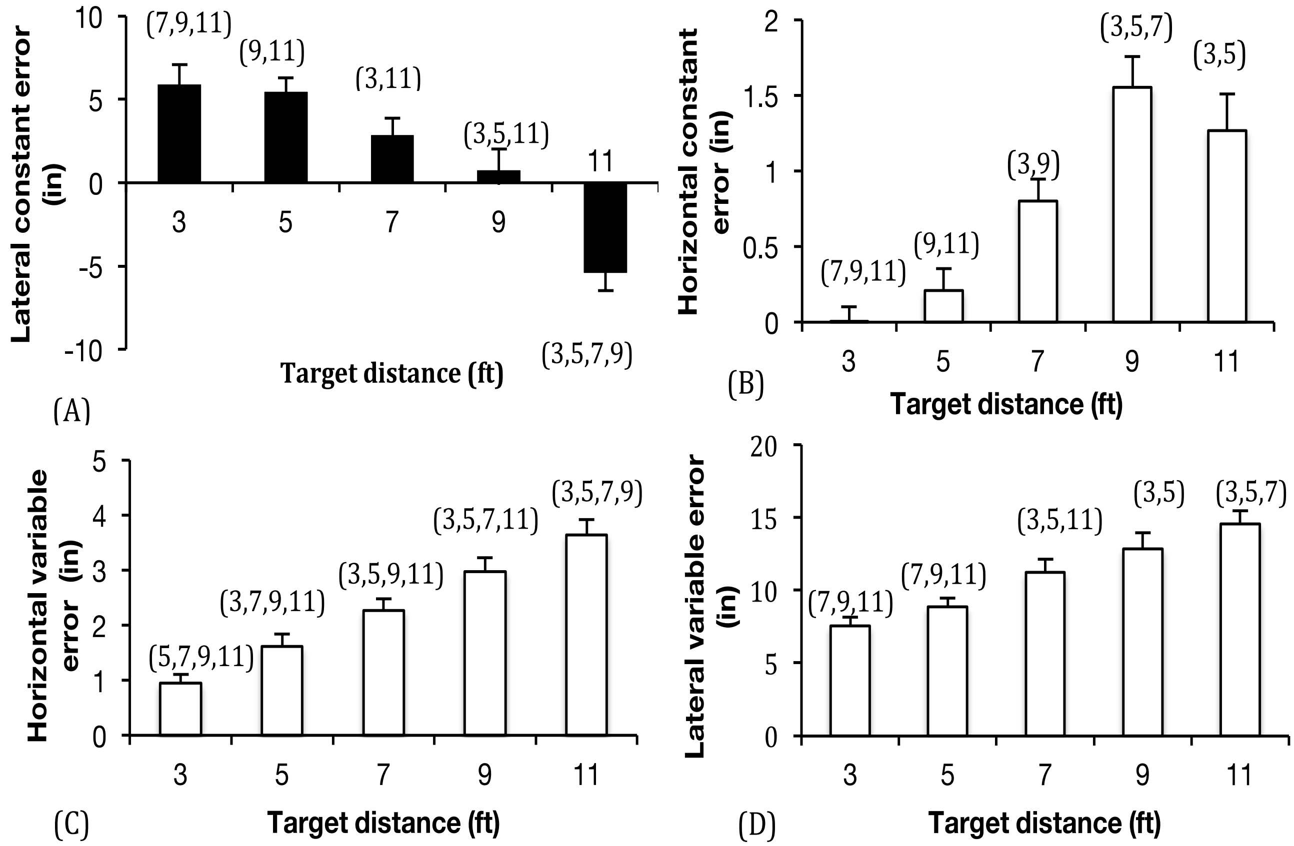

Figure 3.7. **(A)** Lateral (p=0.00, n^2= 0.64) and **(B)** horizontal (p=0.00, n^2=0.466) constant error as well as **(C)** horizontal (p=0.00, n^2= 0.61) **(D)** and lateral (p=0.00, n^2= 0.76) variable error significantly increased with increasing distance. Bars indicate standard error. Numbers indicate the results of pairwise post-hoc comparisons.

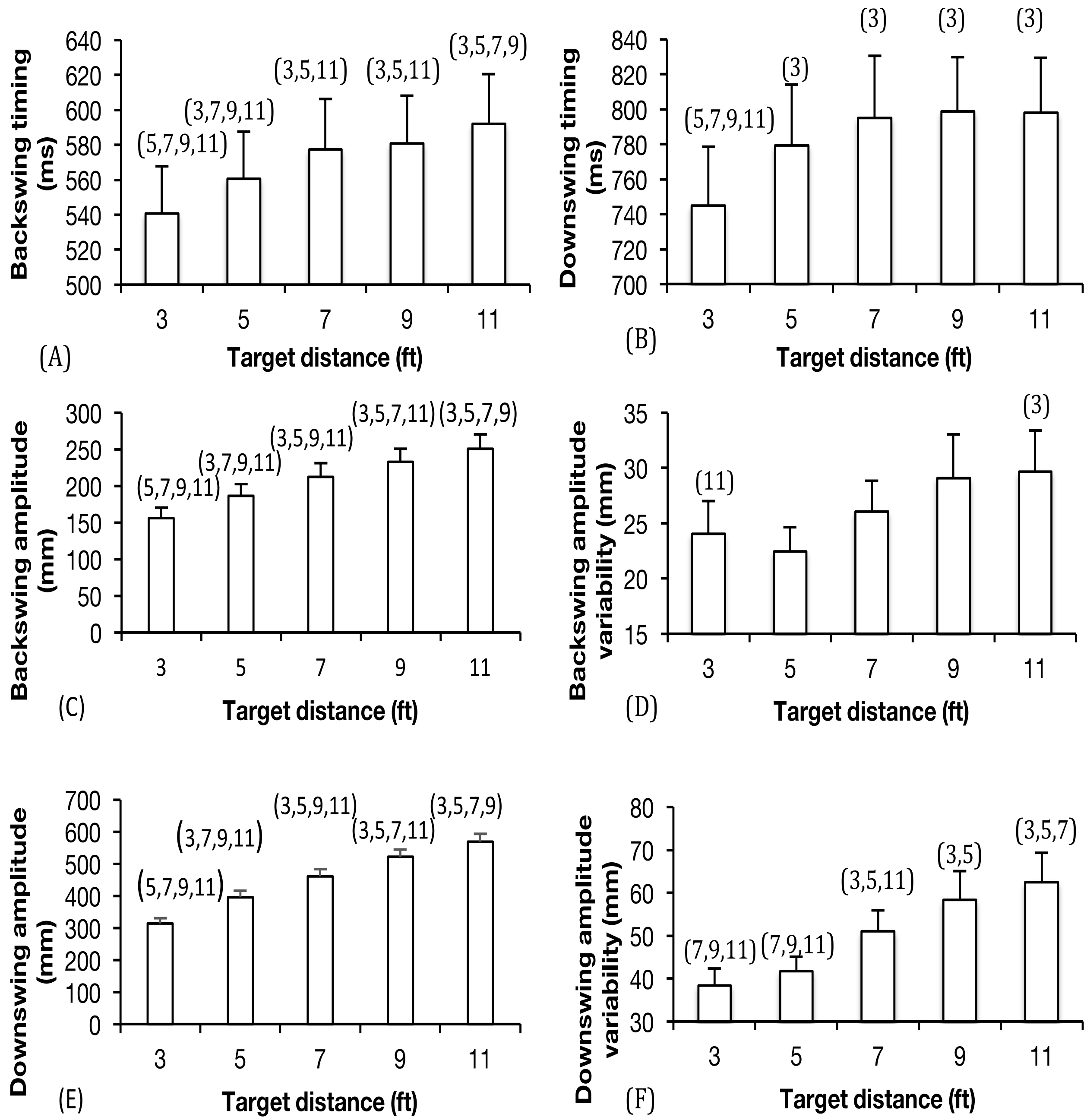

Figure 3.8. (A) Backswing timing (p = 0.00, n^2=0.60), **(B)** downswing timing (ms) (p=0.00, n^2= 0.48), **(C)** backswing amplitude (p=0.00, n^2= 0.91), **(D)** backswing amplitude variability (p=0.00, n^2= 0.24), **(E)** downswing amplitude (p=0.00, n^2=0.96) and **(F)** downswing amplitude variability (p=0.00, n^2= 0.50) showed significant main effects for distance. Bars indicate standard error. Numbers indicate the results of the pairwise comparisons.

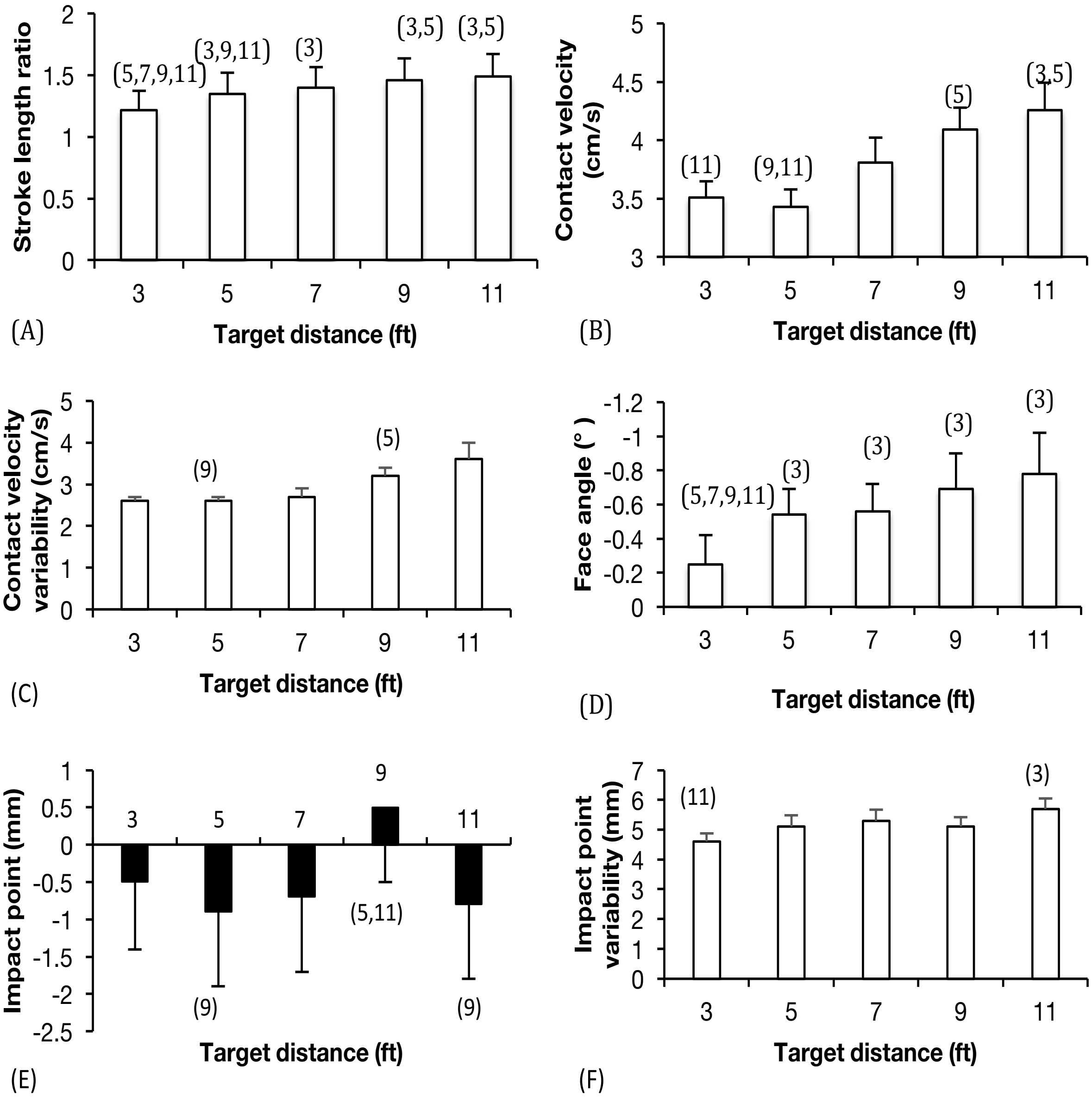

Figure 3.9. **(A)** Stroke length ratio (p=0.00, n^2= 0.57), **(B)** average contact velocity (p=0.00, n^2=0.22), and **(C)** contact velocity variability (p=0.008, n^2=0.172) showed a significant main effect for distance. **(D)** Face angle (p=0.000, n^2=0.334), **(E)** impact point (p=0.02, n^2=0.15), and **(F)** impact point variability (p=0.045, n^2= 0.13) also showed a main effect for distance.

Chapter 4: Discussion

The current study is looking at the effects of changing putter type and distance on the golf putting performance of expert and novice golfers. Expert golfers were defined as those having golf handicaps of 15 or less and 10 or more years of golf experience, while the novice golfers had less than 10 years of golf experience or had never golfed before. The counterbalanced putter was compared with a conventional putter design in order to examine how the new technology may improve the overall kinematics and consistency of putter movement and subsequently, overall performance. Performance was measured using the final resting position of the ball relative to the hole, and whether the ball contacted the target. Schmidt's schema theory has been identified in some discrete sporting tasks and is predicated on the idea of relative timing of each phase of a movement being invariant, with increasing force of a movement coming from varying phase amplitudes (Schmidt, 1975; Gentner, Schmidt, and Ghodsian, 1995). If timing is an invariant feature in golf putting, there should be no changes in the relative timing of phases when weight characteristics or force is changed by using the different putters and relative timing should not change when the distance is increased (Schmidt and Wrisberg, 2008). Relative timing of the best and worst performing participants, determined based on binary performance data, was compared at all five distances and between conventional and counterbalanced putters. Previous studies have indicated two elements required for putting: force and direction control. Force control requires the control of the timing and amplitudes of each phase of the movement, stroke length ratio, and contact velocity, while direction control encompasses the face angle of the putter, putter head rotation, and impact point (Delay et al., 1997; Karlsen, Smith, and Nilsson, 2008; Sim and Kim 2010; Hasegawa et al., 2013).

4.1 Putter type

One of the aspects of the study was identifying kinematic and performance differences between conventional and counterbalanced putters, regardless of a golfers expertise level and what distance they are putting to. There are no published data examining differences between counterbalanced and conventional putters. The counterbalanced putter was brought onto the market when the anchored putting stroke was banned by the PGA, made effective on January 1, 2016. The counterbalanced putter is manufactured by inserting added weight in the shaft just under the grip. Previous research has investigated different weight characteristics in putters such as increased overall shaft weight and weight added closer to the putter head (Karlsen and Nilsson, 2008b; Sim and Kim, 2010). The study identified differences in mean backswing timing, putter contact velocity, face angle, and impact point. Due to increased stability previously believed to be generated by the anchored putting stroke, the variability measures of the counterbalanced putter are of particular interest. The current study found the variability of the putter contact velocity, face angle, and putter head rotation was significantly lower in the counterbalanced putter in comparison to the conventional putter.

Performance results indicate no differences between the counterbalanced and conventional putter when examining the force and direction control performance measures separately. Interestingly, the binary performance of experts with the counterbalanced putter is slightly decreased at the distances of 5, 7, and 9 feet in comparison to the conventional (**Figure 3.1)**. The effect at these distances is directly opposite in the novice population, with the counterbalanced putter improving performance at 5, 7, and 9 ft. This is similar to findings by Gwyn and Patch (1993) who found there were no differences between a long and conventional putter at 9 ft and findings by Pelz (2000) who found the long putter was not, as effective as, a conventional length putter at 20 ft and 40 ft while being better at 3 ft and equal at 9 ft (Hume et al., 2005). The differences between the experts and novices utilizing both putters are a function of the counterbalanced putter being novel to the expert while both putters are novel to the novice group. Despite slightly decreased performance in the expert group, the counterbalanced putter produced a number of advantageous kinematic improvements in comparison to the conventional putter, regardless of target distance or the expertise level of the individual using it.

The increase in the backswing timing (**Figure 3.3A)** and lack of change in the backswing amplitude with the counterbalanced putter indicates the increased weight of the shaft of the counterbalanced putter is resulting in more time being needed to move the putter through the same distance as the conventional putter, which is an indicator of increased performance (Delay et al., 1997). In combination with these aspects, backswing timing and amplitude was consistent between the two putters. Despite the lack of a significant difference in the variability of the phase timing and amplitudes, the counterbalanced putter showed a more consistent movement pattern or trajectory for both the experts and novices in comparison to the conventional putter **(Figure 3.2)**. The lack of a change in the amplitudes also led to a lack of a difference in the stroke length ratio when either putter is used. The relative amplitude of the phases being identified as an invariant feature of the golf putt, in addition to invariant timing when the conventional and counterbalanced putters are compared, provide evidence for the schema theory (**Table 3.1**).

While weight characteristics did not affect most of the timing and amplitudes of the movement, putter contact velocity was decreased and less variable when the counterbalanced putter was utilized (**Figure 3.3B and 3.3C**). Assuming the same amount of kinetic energy needs to be produced regardless of putter in order to ensure the ball reaches the target at any given distance, an increased putter mass would result in a decrease in the velocity required to generate a level of kinetic energy equivalent to that of the conventional putter. It was proposed by Karlsen and Nilsson (2007), the increased weight in the shaft of the putter would produce a larger moment of inertia and result in more force needing to be applied to the putter, in order to achieve the same putter head speed and therefore, ball speed. There may be a difference caused by the location of the increased weight in the counterbalanced putter which is located specifically in the grip rather than dispersed through the entire shaft as in the study by Karlsen and Nilsson (2007). The weight being concentrated in one area of the counterbalanced putter potentially produced a larger moment of inertia, therefore a smaller velocity was required to produce the same amount of kinetic energy in comparison to the conventional putter. The concentrated weight in the shaft of the putter resulted in the contact velocity being more consistent from trial to trial.

The average and within-subject variability of face angle, putter head rotation, and impact point were used in order to examine whether the counterbalanced putter produced less variability in putter movements contributing to the direction in which the ball travels. It was assumed the variability of all direction measures would be decreased in the counterbalanced putter due to the hope of mimicking the stability and consistency of the anchored putting stroke. Previous research identified variability differences in putter head rotation with varying putter head designs (Karlsen and Nilsson, 2008b) and our study has shown the counterbalanced putter will decrease variability in both face angle and putter head rotation, meaning the direction of the ball should be more consistent (**Figure 3.4C and 3.4D**). The average face angle change was also lower with the counterbalanced putter in comparison to the conventional, making the counterbalanced putter more advantageous for the control of face angle, overall (**Figure 3.4A**). While these differences were not reflected in the performance outcomes, hypothetically, more practice could result in more consistent direction control. When participants used the counterbalanced putter, ball contact was made closer to the heel of the putter in comparison to when the conventional putter (**Figure 3.4B**) was used but the counterbalanced putter did not result in less variability in the impact point. Previous research found the influence of the impact point did not affect the balls travel path as much as other elements, particularly face angle (Karlsen and Nilsson, 2008), therefore this result is expected. The change in average impact point may be an advantageous feature of the counterbalanced putter, while it was assumed golfers were beginning the shot by lining up the ball and sweet spot on the putter appropriately, movement may indicate the spot is being adjusted and adjustment is more readily made with the counterbalanced putter in comparison to the conventional, due to the different weight characteristics.

While differences in kinematic measures were identified and primarily attributed to the difference in weight characteristics between the counterbalanced and conventional putter, there were interestingly minimal differences seen in the overall performance of golfers, regardless of distance when comparing the two putters. Most importantly, there were consistency differences seen in the putters' movement trajectory, with the counterbalanced putter showing more consistent movement patterns. The relative timing of each phase was also invariable and together this indicates the schema theory of learning is present within the task of golf putting as different force requirements did not disrupt certain aspects of the skill. Overall, the counterbalanced putter would be beneficial for a golfer seeking to decrease variability in the movement of the putter head, as well as, increasing the consistency of the movement pattern of the putter.

4.2 Expertise level

Expert-novice comparison is an important aspect in determining features which should be emphasized during deliberate practice in order to develop expertise in a skill. Previously identified features of expertise or optimal aspects of performance with changing distance include: increased backswing timing, decreased backswing amplitude, increased downswing amplitude with changing distance, invariant downswing timing, invariant relative timing of all three phases and an invariant stroke length ratio (Delay et al., 1997; Sim and Kim, 2010; Karlsen et al., 2008). The current study found experts had a larger average downswing time and a different stroke length ratio compared to novices and a less variable backswing time. Experts spend more time in the backswing and cover less distance than novices, as well as, they can consistently increase downswing amplitude while maintaining a larger downswing time. A difference between the average impact point between experts and novices was identified. Experts exhibited lower variability in face angle, putter head rotation, and impact point. Qualitatively examining the overall path taken by the putter shows the best performing expert followed a much more consistent movement pattern with the putter, regardless of the putter type compared to the novice (**Figure 3.1**).

The binary performance differences seen between putter type and expertise group (**Figure 3.1**) is not reflected in kinematics or constant and variable error, regardless of distance, and may be due to the added weight of the putter causing experts to think about the skill more. Observations of the participants suggest the weight distracted them by causing thought about the effort needed to successfully complete the shot with the counterbalanced putter. This increase in attentional focus may have caused the breakdown in performance. Beilock et al. (2002) examined experts and novices with the use of a normal and funny putter, and identified a similar performance breakdown in experts when the need to focus on the task was increased. As expected, experts still made more successful shots than the novices did.

The relative timing is not a good measure of expertise due to the individuality of the timing from person to person, but is a good indication of the development of a schema for the movement. The consistency in the relative timing of the phases in each participant, regardless of the putter used or the distance, shows the pattern has been established and other aspects of the putt need to be focused on, in order to improve performance (**Table 3.1 and 3.2**). Aspects such as the stroke length ratio, face angle, putter head rotation, and impact point may be more beneficial to focus on during practice in order to improve performance.

Stroke length ratio is indicative of a golfer’s ability to control the movement of the ball. Unlike novice golfers, the experts in the current study were able increase the amplitude of the follow through phase to almost twice the size of their fore swing as they were putting to the further target distances. Novices consistently matched the size of the follow through with the fore swing (**Figure 3.6A and 3.6B**). Previous literature indicates the follow through should optimally be twice the length of the fore swing (Delay et al., 1997; Sim and Kim, 2010; Karlsen et al., 2008). The follow-through has been identified as important for the control of most sporting tasks involving an implement and the arms, such as the golf swing, in order to ensure the maximal amount of force is being applied during contact (Maddalozzo, 1987). Emphasizing the follow through while executing the movement helps ensure the putter head contacts the ball with the appropriate velocity, while accelerating and not decelerating (Delay et al., 1997). So despite the idea that ability to control outcome ends with ball contact, focusing on the follow through will still affect outcome. The position of the putter relative to the ball at address may have implications for the golfer's ability to control the orientation of the putter as it moves through the backswing and fore swing and may generate problems with controlling the face angle, putter head rotation and impact point at ball contact. All of these features may directly affect the way in which the ball is contacted by the putter, particularly the contact velocity. Previous research has indicated a lower velocity in experts results in increased control due to an improvement in the ability to contact the ball appropriately, making it easier to produce the right amount of force and control the direction of the ball more effectively (Delay et al., 1997; Sim and Kim, 2010). The starting point in the current study required participants to initiate the backswing with the putter flush against the ball, while previous studies gave no instruction, resulting in the novices starting the backswing further away from the ball than experts (Delay et al., 1997). The relationship between the backswing and fore swing amplitudes is such that when the starting point is not controlled, a mismatch between the backswing and fore swing occurs, resulting in significant differences between novice and expert downswing amplitudes. The mismatch may also generate differences in the stroke length ratio of each group. We believe that it would be preferable for the putter to be against the ball during address to promote better control of the putter heads orientation at contact.

Face angle can affect the kinetics of the ball as it leaves the putter, by affecting the roll the ball takes, as well as the overall direction of ball travel (Delay et al., 1997). The findings of the current study suggest while practice may not be needed to correct the average face angle rotation between address and contact, it is required in order to decrease the shot to shot variability of the face angle (**Figure 3.6D**). Karlsen et al. (2008) suggested there should be no change in the putter head rotation, by examining the initial aim of the putter and not examining how the orientation of the putter changes after moving through the backswing and fore swing. Similarly, the current study suggests if efforts are made to ensure the putter head rotation is correct at ball address, a decreased expertise level should not result in more putter head rotation between address and contact (**Figure 3.6E**). Despite this, the novices did show more variability in the putter head rotation therefore practice is needed to increase consistency. Same as face angle and putter head rotation, novices had increased variability in the impact point in comparison to experts (**Figure 3.6F**). Impact point is highly important in overall control of ball travel. While the force parameters, face angle, and putter head rotation may be correct, a fluctuation in the impact point could result in the shot not being successful. This difference in impact point variability was not previously identified in experts and novices. This decreased variability in experts is a function of the experience they have with the putting movement and may be due to experts keeping their head in one place during the whole movement and not moving their head and eyes to follow the putter through the backswing and downswing in the same manner as novices do (Lee et al., 2008, Gonzalez et al., 2012).

Overall, the differences identified between experts and novices indicate relative timing is not a good indication of overall experience with a movement and experts are less variable than novices, based on the trajectory of the putter and aspects such as face angle, putter head rotation and impact point variability. Experts are better at maintaining a follow through that is twice the amplitude of the fore swing, resulting in more consistency in hitting the ball and better overall performance. The slight degradation in performance seen when experts utilize the counterbalanced putter in comparison to the conventional is due to the novelty of the counterbalanced putter and practice is needed to improve performance. The lack of differences between experts and novices in the lateral and horizontal constant and variable error scores as well as average contact velocity which were expected may be due to the way in which experts were identified in the study. Handicap may not be the best way to determine if an individual is an expert putter, due to putting being a very different movement than the swing is.

4.3 Distance

In the current study the mean or average of the kinematic variables related to force control showed similar relationships to that found by Delay and colleagues (1997), and Sim and Kim (2010). The variability measures and the average and variability changes in face angle, putter head rotation, and impact point have not been examined extensively with increasing distance. The current study examined the changes in the kinematics of the putter at 3, 5, 7, 9, and 11 ft, regardless of expertise level and the characteristics of the putter. Overall, with changing distance, the current study identified main effects in face angle. There were only variability differences in backswing and downswing timing, contact velocity, and impact point. There were also expertise dependent changes with increasing distance in the mean downswing amplitude and stroke length ratio. Consistent with variable and constant error data and the changes with kinematics, the binary performance measure deteriorated as distance increased (**Figure 3.1 and Figure 3.7**).

Due to the previously identified importance of generating the appropriate backswing and downswing timing and amplitude in order to produce the necessary amount of force, the variability in the amplitudes are important for controlling the consistency of performance (Delay et al., 1997). The current study found participants were more inconsistent with the backswing and downswing timing and amplitude as the distance to the target increased (**Figure 3.8).** Golfers need to be able to vary the timing and amplitude of the backswing and downswing in order to produce different forces with increasing distance, thus practice should focus on decreasing the variability within each distance.

Contrary to previous findings indicating the ratio should remain the same as distance increases, regardless of putter type or expertise level (Delay et al., 1997; Sim and Kim, 2010), the stroke length ratio did change in the current study (**Figure 3.9A**). Illustrating practice is especially needed at the shorter distances to establish the optimal ratio of 2. As previously discussed this change will have implications on the way in which the ball is contacted and subsequently the direction it takes once it leaves the putter (Maddalozzo, 1987) and novices require practice at the further distances to produce this ratio.

Delay et al. (1997) and Hasegwa et al. (2013) identified backswing amplitude as important for generating contact velocities and concluded contact velocity increased with every increase in distance. In the current study, the lack of a difference in the contact velocity at all distances may be a function of the stimp reading of the putting turf and lack of a real hole (**Figure 3.9B**). Larger contact velocities are not necessary to generate the required ball speed at all distances due to the fast speed of the green as determined by the stimp reading of 10.6. We suspect backswing amplitude variability generated the changes in contact velocity variability we identified. Similar to the average contact velocity, the variability did not consistently increase with every distance, indicating the slight increase in variability should not affect the variability of overall performance (**Figure 3.9C**).

Change in face angle with changing distances showed a tendency to rotate the putter face inwards more as distance increased (**Figure 3.9D).** The ability to control this variable becomes more difficult with increasing distance and may affect ball direction. The changes in mean face angle with increasing distance did not translate to increased variability in the measure which is beneficial for performance. The control of the face angle alone may be more important than being consistent when the distance is varied. Putter head rotation at varying distances, does not need to be a focus during practice because it is not significantly affected by increasing distance. Previous studies did identify increased variability as distance increased, but failed to examine these changes as a shot was made (Karlsen and Nilsson, 2008a) and specifically between address and contact (Sim and Kim, 2010). Previous literature identified a need for practice to develop the ability to control this factor and not drastically influence aim (Karlsen & Nilsson, 2008a). The current study contradicts this suggestion if seeking to improve performance at varying distances as there is no change in the average value or variability of putter head rotation as distance increases. This study showed a change in the average and variability of the impact point as distance increased (**Figure 3.9E and 3.9F**). We suggest there is a greater need for practice, with focus on where the putter contacts the ball relative to the sweet spot, in order to increase consistency at each distance.

Overall, our study identified increasing variability in the backswing amplitude leading to an increase in the variability of the contact velocity as distance increased. Contact velocity was found to not increase with each increase in distance, which may be the result of the stimp reading of the green. Overall, the kinematic changes are consistent with the general relationships identified in previous research. It was also found face angle and impact point were harder to control as distance increased and this should be the focus during deliberate practice.

Chapter 5: Conclusion

This study recruited 10 novice golfers with minimal to no golf experience and 10 expert golfers with handicaps of 2.3-15. Each participant performed a randomized 15 putts at each distance of 3, 5, 7, 9, and 11 feet with a conventional and counterbalanced putter for a total of 75 putts per putter and 150 putts being taken per individual. Kinematic measures and final performance outcome was recorded for every trial and average and within-subject variability measures for each participant with each putter at all five distances were calculated.

5.1 General Conclusions

This is the first study to compare the difference between the counterbalanced and conventional putter. The counterbalanced putter shows less variability which should make it easier for both groups to control the movement of this putter in comparison to the conventional. The relative timing of both experts and novices remained the same when each putter was used indicating the putter type is not manipulating the invariant features of the skill. Practice with both putters is required in order to see the differences between these variables reflected in the final ball position. Interestingly, based on binary performance data the counterbalanced putter resulted in slightly better performance for novices while experts appeared to be worse, due to the novelty of the putter. Regardless of this, the experts still had better performance than novices and had more consistent movement. Deliberate practice for novices should focus on keeping the head looking down and still in order to generate more consistency in the putter heads orientation between address and contact. The increased stability of the counterbalanced putter may be most beneficial for the novice group but more performance increases should occur if the experts practice with the counterbalanced putter. Increasing target distance resulted in performance degradation and a decrease in the ability for the golfer to control the movement of the putter. The invariance of the relative timing that was identified between putters and distances, indicates the motor pattern has been established, regardless of experience with the movement. While practice is needed to improve the overall performance of novices and the experts' performance with the counterbalanced putter, it is likely the relative timing will remain invariant.

Overall, practice should focus on establishing consistency with the movements within each distance with a particular focus on the consistency of face angle, putter head rotation, and impact point if a golfer is seeking to improve their performance, regardless of the putter they use or their level of expertise.

5.2 Validity

This experimental set up was established with a strong consideration for ecological validity. Previous studies have utilized targets such as pylons and spaces marked onto turf-like or normal flooring surfaces. All target distances were generally made visible during the whole testing session. This experimental setup made it possible to make only the currently relevant target visible in order to make it as close to a real life situation as possible. The size and colour of the target were selected to visually mimic the appearance of a regulation golf hole. While these steps were taken to make the environment as close to real as possible, the effect of lie and possible environmental states were not taken into account. For the sake of validity, the target was placed along the exact same line during every trial over the course of the study. To mitigate possible effects of using the same line the participants were encouraged to move around between each trial and due to the way in which the target position was randomized they were usually required to move from the starting point. Overall, the set up allowed for precise measurement of the necessary kinematic variables without being confounded by the participant's ability to read varying aim lines and lies of the green but the lack of a real hole was also a large threat to ecological validity. The lack of environmental factors such as wind and weather also minimize physical and psychological effects.

5.3 Practice Implications

Practice should focus on decreasing the timing, contact velocity and impact point variability at each distance so that the force and direction is more consistent regardless of the distance that the golfer is required to putt. While there were no statistically significant differences in constant and variable error scores between the counterbalanced and conventional putter, the increased consistency in the direction control variables show it may be beneficial for golfers to switch over to the counterbalanced putter if struggling with consistent direction control. The invariant relative timing and the overall lack of a difference in phase timing and amplitudes between putter types provides evidence of the schema theory of learning, while relative timing is not a primary indicator of expertise. The lack of a significant main effect from multivariate testing for expertise level may have been due to the way in which golfers were defined as experts. A technique such as average total putts per round may be a more beneficial way to define an expert at the skill as handicap does take into account the golfers ability to perform other skills in the game of golf.

5.4 Future directions

Data showing changes with distance confirm there is a need to examine whether there is a special distance within golf where performance is either impeded or enhanced. Further analysis should be completed to examine a possible especial effect or deficit in this discrete task.

It appears that the skill of golf putting with a conventional putter does not automatically result in improved performance with the counterbalanced putter for experts. They showed the same general performance levels with the counterbalanced putter in comparison to the conventional but did have improved putter trajectory consistency. Looking at the binary performance measure shows the performance levels being much lower despite the kinematic changes identified in the counterbalanced putter, regardless of group. Future research looking at the effect of learning is necessary and may start to show these relationships between expertise and putter type.

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Appendix A

Golf Study Methodology

A number of different studies have examined different aspects of kinematics and performance outcome of golf putting while manipulating such characteristics as putter head size, putter shaft weight, and distance while sometimes comparing the differences between experts and novices.

Delay et al. (1997) was one of the first studies that looked at the impact velocity of the putter when utilized by experts and novices. Ten expert golfers who were deemed professionals or had a handicap lower than five were compared to 10 novices or controls who had never played golf before, each group had three females and seven males and mean ages were 23-26 years old. Round targets of 5 cm in diameter were drawn onto the testing surface 1, 2, 3, and 4 meters away from the starting point. Data was collected at 200 Hz with a SELPT system and a contactor placed in the testing surface, which was released as soon as the ball was hit, determined contact. Data was collected until 10 correct hits were made per distance.

Beilock, Wierenga and Carr (2002) looked at the effect using a 'funny' and regular putter had on the performance of expert (handicap less than 8) and novice (no experience) golfers with both a single task and dual task paradigm. The 'funny' putter was comprised of a regular putter head and an s-shaped shaft. Shots were taken from nine different locations that were 1.2 m, 1.4 m and 1.5 m away from target. The single task paradigm consisted of taking putts with the two different putters. The dual task paradigm involved taking the putts as in the single task paradigm while performing a task that involved listening for particular sounds and responding to them, which allowed for the attentional focus of the participants to diverted from the putting movement.

Karlsen and Nilsson (2007) tested various shaft weights in 24 club level players (average age 36.5) with average handicaps of 19.4 and an average of 8.4 years experience. The shafts were 100 mg, 420 mg, and 610 mg and shots were made to 4 m, 8 m, and 12 m. Trials were separated into blocks of 10 per distance with 30 trials being completed with one club and then switching clubs. The order of the clubs was randomized but the same distance order was used for all three putters. Putts were actually made in this test and the shots were taken from anywhere in an impact area of 0.3 m diameter. The participants were able to rate the putters in terms of how they felt when they were utilizing them.

Karlsen and Nilsson (2008a) tested 20 elite golfers (1 female) with average handicaps of 0.4 of which 13 were carded professionals. Participants were asked to aim to various targets along different lines in a 120° range around the starting point. Sixteen different distances were chosen in ranging from short distances of 0.4 - 1.2 m and longer distances of 2.5 - 4.5 m. 3D ultrasound was used to measure the difference between the angle of the putter face and a calibration line by picking up a signal from a triplet of 3-70 Hz ultra units on the shaft of the putter. Participants just lined up the shot and let the experimenter know when they were ready and the position was recorded. No balls were actually hit by the participants and no feedback was provided to them. The measure identified was called face angle but it most similar to the measure of putter path.

Karlsen and Nilsson (2008b) tested aiming consistency in 32 club players (2 female) with an average handicap of 11.4±10.8 and 9.1±5.3 years of experience. Participants aimed with 12 different putters (six blade and six mallet) to 16 difference targets ranging from 0.4 -

4.5 metres. No actual putts were taken in this test. One aim to each of the 16 distances were made with each of the 12 putters and while putter order was randomized, the distances were always presented in the same order. Participants were also asked to rate their ability to aim with each of the putters.

Karlsen, Smith, and Nilsson (2008) tested 71 elite golfers (21.7±7.1 years old) with handicaps of 1.8±4.2. Twenty-six of the tested golfers were professionals. Measurements were completed with a 3D kinematical ultrasound measurement system using a 70 Hz triplet attached to the shaft of the putters. The data used was collected both indoors and outdoors on fast and fairly flat greens. Shots were taken at the golfers own pace and with their own putter and the only instructions they were provided was to be as consistent as possible with both the direction and distance of the shot. The shots were completed to an average of 3-4 m and the average number of putts taken per person was 18.3.

Sim and Kim (2010) examined differences between experts and novices at various distances with various putter types. In this study, additional weight on the putters and varied distances were added to the study in order to examine the effect of weight and distance constraints on the different expertise groups, not necessarily to examine the performance at varying distance and putter weights. Five experts golfing teaching professionals (1 female, average age 32.5 years) with single digit handicaps and five novices (1 female, average age 30.6 years) with no golfing experience were tested. Participants were not compensated in any way. Two putters of the same size characteristics were used and one putter had an extra weight added to the rear side of the club head so that the putters weighed 500 and 750 g. The study utilized 2 video cameras capturing data at 60 frames per second and used APAS to generate the 3D motion analysis data. Putting was conducted on an artificial lawn in a calibrated space of 1 m by 1 m by 2 m. Shots made to target distances of 1.7 m, 3.25 m, and 6 m and radial error was calculated for each shot. It is not known if all 3 targets were visible at all times during testing or how the targets were created. It is important to note that this study was unique in the way in which it used the movement phase as an independent variable while other studies examined the phases separately.

Hasegwa, Koyama, and Inomata (2013) utilized 23 amateur golfers (13 women, average age 38.6) with average handicaps of 5.7 and 14.5 years of playing experience to examine the effect that trait anxiety and anxiety inducing situations have on the kinematics of the golfer at various distances. Those with lower than the median on a state anxiety form and changing heart rate were placed in the low anxiety and those above were considered high anxiety. Testing was completed with target distances of 1.25 m, 1.50 m, and 1.75 m to a regulation hole that was cut into a platform covered by artificial putting turf. Two video cameras were utilized and kinematics were analyzed at 60 Hz. Distance was randomized into blocked of 3 and 5 blocks were completed for 15 shots per condition. The high anxiety inducing condition involved being either rewarded or punished for performance levels and completing the testing in front of 12 spectators. At the end of the testing if the goal was achieved they received a payment and if they did not, they were not charged a fee.

Kooyman, James and Rowlands (2013) tested 4 novices and 5 experts. The experts played regularly and/or were members of a golf club. They completed two sets of 15 putts to distances of 1.5 m, 3 m, and 6 m and were provided with temporal feedback between the sets. Data was collected from an inertial sensor unit place on the club at 100 Hz and feedback was generated by a custom made Matlab GUI.

Hladky, Roshko, and Maraj (2014) utilized studied differences between 4 novices (26.3 years old) with 0-16 years of recreational experience and no known handicap and 4 experts (25.3 years old) with 1-16 years experience and self reported handicaps ranging from 0-17 (mean of 8). Kinematics were tracked with three active markers on the putters and collected at 120 Hz by Visualeyez motion tracking system. A set of 15 putts were made to a distance of 3 ft or around 1 m with a conventional blade putter and a conventional mallet putter.

In conclusion, the methods utilized to examine the changes generated in the golf putt with varying distance and golf putter design with various levels of putting expertise are varied. While some studies have examined putting mechanics, they have focused on the average or mean of particular variables and not specifically highlighted variability on all variables. The studies completed by Karlsen and Nilsson (2007, 2008a, 2008b) and Karlsen, Smith, and Nilsson, (2008) did not examine novice golfers in anyway and a number of the studies examining directional variables and their variability did not involve the putting of a ball, just the lining up of the shot.

Appendix B

UNIVERSITY OF ALBERTA

Faculty of Physical Education and Recreation

3-100 University Hall, Van Vliet Complex
Edmonton, Alberta, Canada T6G 2H9

INFORMED CONSENT FORM

Part 1

Title of Project: "Expertise in a discrete motor skill"

Principal Investigator(s): Brian Maraj

Co-Investigator(s): Kateline Hladky, Ran Zheng, Felix Ling

Perceptual Motor Behaviour Lab tel: (780) 492-0578
Faculty of Physical Education and Recreation tel: (780) 492-8649

Part 2

Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached Information Sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate, or to withdraw from the study at any time, without consequence, and that your information will be withdrawn at your request? Data may be removed after collection upon request until August 15th, 2015.	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your information?	Yes	No

This study was explained to me by: ______________________________

I agree to take part in this study:

______________________________ ______________________________
Signature of Research Participant Date

____
Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

______________________________ ______________________________
Signature of Investigator or Designee Date

The information sheet must be attached to this consent form and a copy of both forms given to the participant.

Appendix C

UNIVERSITY OF ALBERTA

Faculty of Physical Education and Recreation

3-100 University Hall, Van Vliet Complex
Edmonton, Alberta, Canada T6G 2H9

STUDY QUESTIONNAIRE

Title of Project: "Expertise in a discrete motor skill"

Principal Investigator(s): Brian Maraj

Co-Investigator(s): Kateline Hladky, Ran Zheng, Felix Ling

Perceptual Motor Behaviour Lab tel: (780) 492-0578
Faculty of Physical Education and Recreation tel: (780) 492-8649

Participant Code:________

Please provide answers for the following:

How old are you? __________

Are you comfortable standing and performing physical activity for the duration of the study?	Yes	No
Do you have normal or corrected to normal vision?	Yes	No
Do you have any known neurological problems?	Yes	No
Do you golf with a right handed putter?	Yes	No
Do you have a known golf handicap?	Yes	No

What is your golfing experience level? Include years of experience, average rounds played per years, and handicap, if applicable.

____

Appendix D

Table D1. Participant Characteristics. Note: N and E dictate novice or expert designation

Participant ID	Sex (M/F)	Age (yrs)	Experience (yrs)	Rounds per year	Handicap
N1	M	26	0	0	N/A
N2	M	19	0	0	N/A
N3	M	27	0	0	N/A
N4	F	27	0	1	N/A
N5	F	29	0	0	N/A
N6	F	20	5	1	N/A
N7	F	44	5	2	N/A
N8	F	24	5	4	N/A
N9	M	25	0	0	N/A
N10	M	31	0	0	N/A
E1	M	58	35	60	11.2
E2	M	23	11	12.5	6
E3	M	25	10	6	12.5
E4	M	21	N/A	10	15
E5	M	45	30	100	2.3
E6	M	65	30	20	15
E7	M	19	12	50	8
E8	M	24	10	35	9
E9	M	55	43	60	9
E10	M	54	40	15	9

Appendix E.

UNIVERSITY OF ALBERTA

Faculty of Physical Education and Recreation

3-100 University Hall, Van Vliet Complex
Edmonton, Alberta, Canada T6G 2H9

Expertise in a discrete motor task

Dear Participant,

Thank you for your interest in this study. This letter describes the research purpose and the rights and responsibilities of being a participant. It also outlines what is involved if you decide to participate. We encourage you to direct any questions about this study toward us at any time. Our names and contact information are listed below.

Brian Maraj brian.maraj@ualberta.ca
Kateline Hladky kateline@ualberta.ca
Ran Zheng rzheng1@ualberta.ca
Felix Ling fling1@ualberta.ca

The purpose of this study is to investigate the differences between experts and novices in the discrete motor task of golf putting. Control of force and direction is required to successfully complete a putt at any distance.

Participation in a testing session will span up to 2 hours. You will be using two putters to complete putts at numerous distances from a target. Putts will be completed on a 10 by 12 foot piece of EZ-Turf. Testing will take place in the Perceptual Motor Behaviour Lab at the University of Alberta (4-245 Van Vliet Complex). Please ensure that you are wearing any corrective lenses required for normal eyesight.

We will provide you with each putter to be used and all putters will be marked with small markers with removable pieces of Velcro. The markers will be attached to a battery pack on a belt that you will be asked to wear for the duration of the testing session.

The aim of the putting task is to get the ball to come to a rest on or against a target. You will complete 2 minutes of practice with each putter. You will then complete 75 trials with each putter at 5 distances in blocks of 15 with a 1 minute break between blocks and a 2 min break between putters for a total of 150 putts over the testing period.

There will be a draw amongst the top 5 performers in each group for a prize valued at $50.00 - $60.00. The odds of winning are 0.1 or 10% for each participant.

There will be no immediate benefit but overall results may be of interest. This research will add to a fast growing area of knowledge concerning how putter design may affect player performance and how performance changes based on the expertise of the participant.

There is minimal risk associated with participation in this study. The possibility of eye strain and joint injury can be avoided by listening the guidance of the research team. Any physical or mental discomfort should be mentioned to the team so that steps can be taken to reduce its effect. If muscular fatigue occurs you will be provided with a longer break period.

Appendix F

Table F1. Example of trial order and break schedule

Putter 1	4	4	2	2	5
	3	5	3	1	3
	5	2	4	3	1
	2	3	5	4	4
	1	1	1	5	2
			Break		
	4	3	1	3	1
	5	2	3	5	5
	3	4	4	1	4
	2	1	5	4	2
	1	5	2	2	3
	Break			Break	
	4	1	2	1	4
	5	3	3	5	5
	1	2	5	4	3
	3	4	4	2	2
	2	5	1	3	1
		Break			Break
Putter 2	5	1	5	4	2
	2	3	4	3	1
	1	2	1	1	3
	3	5	2	2	5
	4	4	3	5	4
			Break		
	4	3	5	1	3
	3	1	4	4	5
	5	4	3	3	1
	2	5	2	2	4
	1	2	1	5	2
	Break			Break	
	1	4	1	2	5
	4	1	3	3	1
	3	5	2	5	4
	2	2	5	4	2
	5	3	4	1	3
		Break			

Appendix G

Table G1. Mean kinematic variables based on group (expert/novice), putter type (conventional/counterbalanced), and target distance (3, 5, 7, 9 and 11 ft).

Group	Novice										Expert							
Putter	CV					CB					CV							
Distance (ft)	3	5	7	9	11	3	5	7	9	11	3	5	7	9	11	3	5	7
Force Control																		
BST	482	493	512	518	520	504	523	528	537	550	579	598	618	619	634	597	629	651
(ms)	(34)	(34)	(36)	(35)	(35)	(43)	(42)	(46)	(44)	(46)	(34)	(34)	(36)	(35)	(35)	(43)	(42)	(46
DST	628	655	672	677	656	640	663	674	682	682	849	906	905	921	930	862	894	92
(ms)	(48)	(53)	(51)	(47)	(45)	(50)	(49)	(51)	(44)	(47)	(48)	(53)	(51)	(47)	(45)	(50)	(49)	(51
BSA	164	194	224	249	262	163	199	228	248	268	149	173	200	215	235	148	178	19
(mm)	(20)	(22)	(25)	(23)	(26)	(22)	(25)	(28)	(29)	(31)	(20)	(22)	(25)	(23)	(26)	(22)	(25)	(28
DSA	288	364	421	484	513	283	353	418	470	501	347	434	503	569	635	337	430	50
(mm)	(24)	(28)	(30)	(32)	(37)	(26)	(29)	(34)	(35)	(35)	(24)	(28)	(30)	(32)	(37)	(26)	(29)	(34
SLR	0.90	1.01	1.05	1.08	1.08	0.92	0.95	1.00	1.08	1.05	1.56	1.81	1.79	1.88	1.94	1.50	1.63	1.7
	(0.22)	(0.27)	(0.26)	(0.25)	(0.27)	(0.22)	(0.23)	(0.22)	(0.25)	(0.26)	(0.22)	(0.27)	(0.26)	(0.25)	(0.27)	(0.22)	(0.23)	(0.2
CV	4.49	4.89	4.77	5.08	5.20	3.18	2.96	3.96	3.91	3.74	3.84	3.38	3.81	3.97	4.91	2.54	2.48	2.7
(cm/s)	(0.28)	(0.33)	(0.45)	(0.32)	(0.50)	(0.29)	(0.22)	(0.44)	(0.35)	(0.38)	(0.28)	(0.33)	(0.45)	(0.32)	(0.50)	(0.29)	(0.22)	(0.4
Direction Control																		
FA	-0.48	-0.95	-0.86	-1.40	-1.36	-0.29	-0.60	-0.69	-0.74	-0.85	-0.23	-0.41	-0.43	-0.51	-0.59	-0.01	-0.21	-0.2
(deg)	(0.33)	(0.24)	(0.26)	(0.38)	(0.39)	(0.21)	(0.23)	(0.25)	(0.27)	(0.31)	(0.33)	(0.24)	(0.26)	(0.38)	(0.39)	(0.21)	(0.23)	(0.2
PR	1.51	0.70	1.40	1.04	0.42	1.36	1.58	1.30	1.51	1.72	0.62	0.62	0.94	0.33	0.46	1.25	0.61	1.0
(deg)	(0.47)	(0.50)	(0.57)	(0.66)	(0.67)	(0.48)	(0.54)	(0.66)	(0.61)	(0.69)	(0.47)	(0.50)	(0.57)	(0.66)	(0.67)	(0.48)	(0.54)	(0.6
IP	-2.22	-2.45	-2.12	-0.68	-2.77	-3.47	-4.88	-4.06	-1.72	-4.35	1.56	1.64	1.97	1.82	1.79	2.08	1.93	1.4
(mm)	(1.23)	(1.76)	(1.43)	(1.49)	(1.43)	(1.42)	(1.52)	(1.68)	(1.63)	(1.73)	(1.17)	(1.15)	(1.39)	(1.27)	(1.27)	(1.51)	(1.38)	(1.4

Table G2. Within-subject variability of kinematic variables based on group (expert/novice), putter type (conventional/counterbalanced), and target distance.

Group	Novice										Expert							
Putter	Conventional					Counterbalanced					Conventional					Counterbalan		
Target (ft)	3	5	7	9	11	3	5	7	9	11	3	5	7	9	11	3	5	7
Force Control																		
BSTV	47	54	50	49	57	61	50	46	50	48	88	79	79	89	86	82	83	92
(ms)	(31)	(31)	(31)	(31)	(32)	(33)	(34)	(34)	(33)	(32)	(28)	(28)	(28)	(28)	(29)	(30)	(30)	(31)
DSTV	68	91	76	83	72	72	72	74	91	76	89	80	89	73	80	82	78	89
(ms)	(11)	(18)	(17)	(15)	(14)	(10)	(13)	(14)	(17)	(13)	(11)	(18)	(17)	(15)	(14)	(10)	(13)	(14)
BSAV	30	31	36	40	41	31	29	32	32	33	19	13	19	26	25	17	16	18
(mm)	(5)	(4)	(4)	(9)	(7)	(4)	(4)	(4)	(4)	(5)	(5)	(4)	(4)	(9)	(7)	(4)	(4)	(4)
DSAV	40	53	59	70	74	41	43	56	65	61	43	36	43	48	58	30	36	46
(mm)	(8)	(7)	(8)	(9)	(11)	(5)	(4)	(7)	(11)	(12)	(8)	(7)	(8)	(9)	(11)	(5)	(4)	(7)
SLRV	0.26	0.27	0.23	0.25	0.22	0.29	0.25	0.22	0.23	0.23	0.30	0.31	0.29	0.32	0.31	0.28	0.25	0.27
	(0.05)	(0.05)	(0.04)	(0.06)	(0.05)	(0.05)	(0.07)	(0.06)	(0.04)	(0.05)	(0.05)	(0.06)	(0.04)	(0.06)	(0.05)	(0.07)	(0.06)	(0.04)
CVV	3.36	4.13	3.11	3.79	3.94	2.33	2.01	2.55	3.15	3.02	2.86	2.39	2.91	3.25	4.87	1.87	1.80	2.08
(cm/s)	(0.28)	(0.36)	(0.37)	(0.40)	(1.16)	(0.22)	(0.20)	(0.32)	(0.28)	(0.33)	(0.28)	(0.36)	(0.37)	(0.40)	(1.16)	(0.22)	(0.20)	(0.32)
Direction Control																		
FAV	1.75	1.72	1.67	1.85	1.88	1.11	1.09	1.23	1.23	1.22	1.64	1.64	1.61	1.62	1.68	0.72	0.76	0.78
(deg)	(0.11)	(0.13)	(0.10)	(0.16)	(0.18)	(0.09)	(0.08)	(0.11)	(0.08)	(0.12)	(0.11)	(0.13)	(0.10)	(0.16)	(0.18)	(0.09)	(0.08)	(0.11)
PRV	3.37	3.21	3.29	3.86	3.99	2.81	2.73	2.76	2.53	3.13	2.96	3.02	2.78	2.81	2.64	1.75	1.60	1.78
(deg)	(0.22)	(0.26)	(0.23)	(0.24)	(0.24)	(0.20)	(0.21)	(0.20)	(0.16)	(0.24)	(0.22)	(0.26)	(0.23)	(0.24)	(0.24)	(0.20)	(0.21)	(0.20)
IPV	6.29	7.05	7.36	7.64	7.55	5.98	7.09	6.86	6.21	7.90	3.13	3.09	3.44	3.21	3.62	3.15	3.31	3.53
(mm)	(0.45)	(0.59)	(0.56)	(0.61)	(0.71)	(0.43)	(0.61)	(0.55)	(0.42)	(0.48)	(0.45)	(0.59)	(0.56)	(0.61)	(0.71)	(0.43)	(0.61)	(0.55)

Table G3. Lateral and horizontal constant and variable error measurements for novice and expert groups at 3, 5, 7, 9, and 11 ft target distances with a conventional and counterbalanced putter

Group	Novice														
Putter	Conventional					Counterbalanced					Conventional				
Target (ft)	3	5	7	9	11	3	5	7	9	11	3	5	7	9	11
Lateral Direction															
CEY (in)	3	5	1	0	-7	5	4	1	1	-7	10	7	7	2	-2
	(2)	(1)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(1)	(2)	(2)	(2)
VEY (in)	9	11	14	19	18	10.	11	17	16	18	6	6	7	8	11
	(1)	(1)	(1)	(2)	(2)	(1)	(1)	(2)	(2)	(1)	(1)	(1)	(1)	(2)	(2)
Horizontal Direction															
CEX (in)	-0.1	-0.1	1	2	2	0.1	0.4	1	2	2	-0.1	0.2	0.6	1	0.4
	(0.2)	(0.3)	(0.3)	(0.3)	(0.4)	(0.1)	(0.2)	(0.3)	(0.4)	(0.5)	(0.2)	(0.3)	(0.3)	(0.3)	(0.4)
VEX (in)	2	3	3	4	5	2	3	3	4	5	0.2	0.5	1	2	2
	(0.3)	(0.4)	(0.4)	(0.4)	(0.5)	(0.2)	(0.3)	(0.3)	(0.4)	(0.4)	(0.3)	(0.4)	(0.4)	(0.4)	(0.5)