Golf putting and postural stability: stance width influences on static postural stability and putter kinematics

Jesse David Chiero
The University of Toledo
A Thesis

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Golf Putting and Postural Stability: Stance Width Influences on Static Postural Stability and Putter Kinematics

By

Jesse David Chiero

Thesis submitted in partial fulfillment of the requirements for

The Masters of Science Degree in Exercise Science

______________________________
Dr. Charles Armstrong, Committee Chair

______________________________
Dr. Philip Gribble, Committee Member

______________________________
Dr. Brian Pietrosimone, Committee Member

______________________________
Dr. Patricia Komuniecki, Dean
College of Graduate Studies

The University of Toledo
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An Abstract of
Golf Putting and Postural Stability: Stance Width Influences on Static Postural Stability and Putter Kinematics

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Objective: To examine base of support characteristics of three stance conditions, their impact on static postural stability measured by COP-E_{xy} and their influence on the putter kinematics associated with directional control in putting. The measures were performed on skilled amateur male and female golfers. The putter kinematics of initial aim, face angle at impact, putter path through impact and impact spot were measured for all stance conditions where comparisons and associations were investigated. Design and Settings: A crossover study was performed, with randomization of each stance condition (wide, narrow, self-selected) for each subject and differences across dependent variables of directional putter kinematics, static postural stability and putt outcome were investigated. Significance was set at p<0.05. A linear regression was performed between directional putter kinematics and COP-E_{xy}. All testing was done in an indoor golf facility, on a flat (Player’s Turf) synthetic putting surface, with the subjects using their own putter. Subjects: 18 NCAA Division I collegiate golfers (9 male, 9 female) maximum
age range (18 – 23 years) participated in this study. **Measurements:** Three stance conditions were determined for each subject (self-selected, narrow, and wide). To insure consistency among trials, each stance condition was marked on a stance grid prior to testing, and twenty putting trials at each stance condition were recorded. To assess putter kinematics the SAM PuttLab ultra-sound technology was used. For static postural stability measures the Tekscan F-Scan pressure instrumentation sensor system was used. Putt outcomes (makes/misses) were also recorded to measure functional putting performance. **Results:** The three stance width conditions, were significantly different from one another (p<0.000) No statistically significant differences were found for the putting kinematic variables, static postural stability or putt outcome, when compared across the stance conditions. The linear regression analysis showed statistically significant, moderate positive relationships between the variables of face angle at impact (p=0.047), putter path direction (p=0.004) and impact spot (p=0.045) and the variable of total COP-E_{xy}. Regression analysis also yielded coefficient of determination values (R Square) for impact spot of 0.115, 0.113 for face angle, 0.195 for putter path direction through impact and 0.013 for initial aim. **Conclusion:** the results indicated significant relationships between the magnitude of COP-E_{xy} and face angle at impact, putter path direction and impact spot. These results indicate that positive changes in putting accuracy kinematics were associated with greater postural stability. Supporting this, the results suggest that total COP-E_{xy} decreased as the base of support was increased, although this finding was not statistically significant. In general, the results provide only limited support for position that skilled collegiate golfers displayed biomechanically more optimal putter kinematics when using their self selected stance and had the least
biomechanically optimal putter kinematics with a wide stance. This appears to limit the
link that can be drawn between postural stability and putter kinematics.
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Chapter 1

1.1 Introduction

Putting is a precision skill within a game that demands precision. As with every facet of golf, putting has common methods of execution and a specific desired outcome. Putting demands fine motor control and requires exacting precision and pinpoint accuracy. With putting, the target is three and one quarter inches in diameter, compared to other common shots such as the tee-shot or approach shot where the target may average thirty yards in width or more. Accuracy in putting performance is measured in inches and centimeters, where tenths of degrees separate makes and misses. At the highest level of collegiate golf the top fifty putters in the United States average 28.9 putts per round.\textsuperscript{11} Putting is the most prevalent shot in a round of collegiate golf accounting for 39.44\% of all strokes.\textsuperscript{11} Given the high prevalence of putting during a competitive round of golf and its exacting nature, developing a sound understanding of the factors that produce optimal stroke mechanics should contribute to enhanced putting performance.

A major factor influencing the likelihood of success in putting is that involving the path of the putter during the putting stroke. There are several generally accepted techniques that are thought to produce specific putter kinematics with respect to the
puter’s path and its rotation as it is directed through the stroke. The most prevalent
techniques include putter paths characterized by a straight back strait through path, an
inside to inside path, and an inside to square path. Each of these path techniques has
associated rotational characteristics. The strait back strait through path has no putter head
rotation, characterized by a putter head that remains directed down the target line
throughout the entire stroke. The inside to inside path corresponds to the putter head
rotating such that putter head remains perpendicular to the curvilinear path created during
the backswing and continuing this rotational characteristic through until the completion
of the follow through. The inside to down the line path is a combination of the two
previous methods. The putter head rotates in the same manner as the inside to inside path
during the backswing until ball contact, after which the putter head no longer rotates for
the duration of the follow through, and the putter path finishes down the target line.
While these techniques are widely accepted and frequently taught to golfers, little
research exists to validate their effectiveness.

Mathematical modeling of the putting stroke has introduced two models to
improve the understanding of the mechanics of the movement. The two models
presented are pendular and planar. The planar model simply and accurately models both
the inside to inside and square to square putting techniques. The pendular model better
suities the straight back straight through method. Although practical applications of these
models have been used prior to their validation, with these models there is now a clear
understanding of maximally efficient and optimal putter kinematics.
1.2 Statement of the Problem

Having a concrete understanding of the appropriate putting techniques is an important facet to putting performance. However, another equally important facet is the player, the engine that drives the putting stroke. This is the area where our understanding of putting performance is less extensive. What factors affect the player’s kinematics, which in turn largely define the putter and ball kinematics? Notably these factors would include features associated with the player’s specific anatomy, the putter they choose to employ, and their set-up or how they address the ball. This research is focused on one of these factors, the set-up, to examine its influences on putting performance.

With most players the set-up is chosen based on a feeling of comfort, a sense of relaxed physical state that coincides with a relaxed mental state. The set-up notably concerns grip, anatomical posture, stance, and ball orientation or ball position. The stance the player assumes dictates how the player is orientated to the ball as well as their ability to control the center of mass (COM) relative to the base of support. This is known as postural stability.

Measuring motion of the COM describes the state of stability the player has and is quantified by examination of the displacement of the center of pressure (COP). COP is the center of distribution of the total force applied to the ground. It constantly moves in relation to movement of the line of the center of gravity (COG), which is the vertical extension of COM to the ground. COP is therefore the measure that provides information on the control process or strategy used by the player for postural stability.
Interestingly, research on postural sway as a constraint in the precision task of aiming has linked body orientation in relation to the target to specific directions of body sway. Stance orientation similar to that seen in archery and rifle shooting was investigated. They stated that when the participant was oriented where their frontal plane was parallel to the target medio-lateral sway had to be minimized (to increase aim accuracy) and when they were oriented such that their frontal plane was perpendicular to the target, the orientation used in putting, antero-posterior sway had to be minimized. Further this study determined that some amount of postural variability (movement) is needed to ensure stability during quiet standing while aiming precisely. Also, when postural activity (movement) is reduced in one direction during aiming it is compensated for by activity in the opposite direction. Without a clear understanding of COP movement during the putting stroke we are unable to apply findings in related research that may benefit understanding and performance in putting.

1.3 Statement of the Purpose

The putting stroke itself requires the player to control fine motor movement. Joint position awareness, joint integrity, joint stability and kinesthetic sense all play apart in the sensory component of fine motor control. The joints that contribute to the movement of the putter include the shoulder, the elbow, the distal radius and ulnar joints, and the numerous joints of the wrist and hand. The combination of movement and stabilization at these joints produces the movement of the putter as it progresses throughout the stroke.

In other fine motor skills such as archery and rifling, the same is true. Each of these skills requires exact control of the small joints of the hands, the wrist, the elbow, and the shoulder in order to produce the desired result, a strike of the target. These skills,
including putting, also require static postural stability, which is controlled primarily by the joints of the lumbar spine, the hip girdle and hip joint as well as the joints at the knee and ankle. Stability at these joints provides postural integrity which functions to control COP movement and balance. With optimal control of static postural stability produced by the collective effort at each joint the movement of the putting stroke can be executed with high precision. This investigation aims to advance the understanding of how static postural stability influences putter kinematics during the putting stroke.

The purpose of this research was to investigate the impact of postural stability, as defined through quantification of COP, on the key putting directional determinants of aim, impact spot, face angle at impact, and putter path throughout the putting stroke on Division I collegiate golfers. Due to the small margin for error between a made putt and a missed put, we predict that small or unnecessary COP- \( E_{xy} \) will impact putter kinematics negatively causing less proficient putting. This study will investigate how three different stance conditions impact putter kinematics, static postural stability measures and putting performance.

1.4 **Significance of the Study**

This study compared how changes in base of support influenced putter kinematics, postural stability and putt outcomes, and how these variables may be related to each other. Currently, no research has been conducted to further the scientific literature on the linkage between these variables. Therefore, the results of this investigation may provide new insights into the nature of the relationship between these variables. These results have implications in golf instruction that will make meaningful contributions to scientific golf research.
1.5 Research Hypothesis

1. The wide stance width condition will produce significantly better overall mean scores for each of the key putting parameters, followed by that of the self selected stance width condition and then the narrow stance width condition.

2. The wide stance width condition will produce significantly better total COP scores compared to that of the self-selected and narrow stance conditions.

3. Decreased COP displacement will correspond to significantly lower mean scores for each of the key putting parameters.

1.6 Operational Definitions

A/P = Anterior/Posterior

M/L = Medial/Lateral

COP = Center of Pressure

COP-Ex = Center of Pressure Excursion in the frontal plane

COP-Ey = Center of Pressure Excursion in the sagittal plane

COP-Exy = Total Mean Center of Pressure Excursion in the sagittal and frontal planes

Initial Aim = the orientation of the putter face before the initiation of the stroke in relation to the center point of the hole measured in degrees.

Face Angle at Impact = the orientation of the putter face, in relation to the center point of the hole, at impact with the ball measured in degrees.
Impact Spot = the horizontal point of contact between the ball and the putter measured in millimeters

Putter Path Direction = a twenty centimeter linear segmentation of the entire putting stroke whose linear path is measured in degrees away from the center point of the hole.
Chapter 2

2.1 Literature Review

2.2 Postural Stability and Performance

In putting as with other fine motor tasks the ability to maintain postural stability is a function of the positioning of the head, trunk and appendages in the peripheral environment. The positions of these segments are relayed via somatosensory input which is combined with vestibular and visual input to the brain where the input is processed and postural stability is maintained. Depending on the movements required and the environment, varying degrees of emphasis are placed on each input. For putting and precision skills like it the peripheral environment is relatively fixed, the base of support is static, the movements are small and controlled and the outcome is accuracy dependent.

The sensorimotor system during a putt provides valuable postural information on the positioning, orientation and movement of body segments their joints and their muscles. Specifically, this system provides sensory information from the joints of the lower extremity and trunk to ensure a stable support and deliver balance adjustments resulting from the perturbation of the putting stroke. Concurrently, sensorimotor information is collected and relayed to the brain in respect to the small controlled
movements needed from the joints of the upper extremity to power the putting stroke. Collectively, these somatic stimuli once processed result in a movement that is both balanced and precise.

Clearly similarities exist between the tasks of archery, rifle and pistol shooting and golf, in that all involve precise control of an implement that is intended to project an object at a target. Currently, archery, rifle and pistol shooting research have shown links between performance and static postural stability. In one such study of skilled junior and senior archers it was found that M/L COP excursion had the strongest relationship to performance.\textsuperscript{26} The archers who performed the best had the lowest levels of COP excursion. Also, it was shown that the junior archers who had the greatest COP displacement showed decreased performance in accuracy.\textsuperscript{26}

Current investigations into the effects of differing stance widths on pistol shooting performance found M/L COP excursion and speed were reduced as stance width decreased. This study also found aim (center of gravity fine) was significantly improved at the narrower stance. These findings suggested that, among national-standard air pistol shooters, a narrower stance yielded better stability for the shooter and improved aim.\textsuperscript{12}

Related rifle shooting performance research has shown that postural stability is related to ability level. Specifically, national top-level rifle shooters exhibited lower movement of the center of force (COF) than naïve shooters. They also found significant differences in naïve shooters most accurate shots and their least accurate shots in regard to movement of COF.\textsuperscript{9} Another investigation of novice rifle shooters examined the relationship between postural balance and gun barrel stability. Measures of stability were M/L and A/P sway velocity. Measures of aiming were horizontal and vertical deviation
from the aiming point. There was evidence in this study that postural balance was related to shooting accuracy, especially among inexperienced shooters, and 26% of the variability in aim could be attributed to postural stability.\(^2\) Also, a comparison of competitive shooters and an untrained control group revealed the competitive shooters had better stability than the controls, and that this was attributed to assiduous training aimed to improve postural stability.\(^1\)

An investigation of six elite shooters postural sway, aim point fluctuation and performance in rifling found that performance decreased with increased COP displacement as a measure of total bodysway.\(^6\) They also found 22-40% of performance and 20-74% of aiming fluctuation could be predicted by body sway, respectively.\(^6\) The research into these respective skills has shown a clear relationship between balance and performance, where increased balance was related to improved performance, and the ability to aim precisely with decreased stability fluctuation. With similarities between golf putting, archery and rifle and pistol shooting it is logical to conclude that similar relationships should exist in golf. Thus, this research aims to establish the relationship between static postural stability, putter kinematics and putting performance.

The scientific literature on postural stability in golf has mainly concentrated on the full swing. The importance of proper stability and weight shift in the full swing is well established, although there are some discrepancies. Research includes investigations into different swing styles and COP patterns with various clubs.\(^4\) This study used golfers of various skill levels, and quantified COP movement throughout their swings for three different clubs. Their COP movement was quantified and termed either ‘forward’ or ‘reverse’ depending on whether the COP moved toward the front foot during the
downswing or not. They found that nearly all participants used the same swing style that produced the same forward or reverse COP movement pattern for all three clubs. This study also found golfers that used the reverse swing positioned their center of pressure nearer to their toes at ball contact compared with golfers that used the front foot swing. 

Similar research reported the ground reaction force (GFR) characteristic that were associated with efficient and powerful golf swings. These included a higher GFR in the rear foot during the backswing and higher GFR in the front foot at impact and though the finish of the swing. These GFR’s differed in magnitude and timing between low and high handicapped players, where lower handicapped players showed higher GRF’s compared to higher handicapped players. These results were supported by similar investigations into GFR among differing skilled players. As COP movement is a reflection of variations in GRF, this research seems to support the link between COP movement and performance.

Interestingly, three similar studies comparing balance sway and weight shift among golfers of different skill levels had contradictory findings. From their findings each concluded that, balance and weight shift were not significantly different among golfers of different skill. 

Further research of COP movement investigated how force patterns exerted on a golf club were coordinated with the golfer's weight shift. Here the data indicated weight shift is relatively independent from the club head force timing pattern, where weight shift patterns show variability but the club force timing pattern does not. Collectively this research has demonstrated that weight shift and the corresponding kinematic measures
are inherently a part of a powerful efficient golf swing with some difference regarding the specific characteristics of the measures.

The scientific literature on postural stability in golf putting is less substantial. A 2008 study investigated putting outcomes for twelve expert golfers, and the association between stability and sensorimotor electroencephalographic (EEG) rhythms. In the study they investigated how the sensorimotor alpha and beta rhythms were related to upright balance and fine arm and hand motor control during the putts of expert golfers. They reported that body sway was similar for made and missed putts, concluding that physiological systems associated with stability (visual and vestibular) were not essential for successful performance in putting.

This study also examined cerebral EEG rhythms to determine the impact on cortical control on the putting motion. Their results indicated that high frequency alpha rhythms but not low frequency waves are specifically implicated in the fine motor control behind successful putts. These findings suggest that low frequency alpha rhythms associated with general arousal, attention, and effort do not impact putt outcome.

Further they found high frequency alpha waves over the right primary sensorimotor cortex and medial prefrontal motor areas where at maximal values during successful putts. These findings implicate fine cortical control of the left arm and hand movements in successful putts. They also suggest that high levels of high frequency alpha rhythms in areas of the motor cortex associated with planning, selection and regulation of learned skills was associated with successful putting outcome.

Another study investigated player’s weight distribution and COP during the putting stroke in professional and amateur golfers. Here foot pressure data for thirty
elite PGA tour professionals and amateur players was recorded. Measures of postural stability included both M/L and A/P COP excursion as well as A/P and M/L weight distributions for six successful putts from twenty five feet. The results showed that professionals demonstrated more evenly spread medial-lateral weight distribution (p<.05) than amateurs, while amateurs appeared to evidence more balanced anterior/posterior weight distribution, although this finding was not significant. It may be the case that with putting, higher skilled players migrate to a set-up position that evenly distributes weight medio-laterally which offers a more stable base from which to execute the putt.

Considering COP movement during the backswing, forward swing, and finish phases of the putting stroke, the same study showed that professionals demonstrated smaller COP displacement at each phase and had significantly smaller COP displacement in the forward swing, the finish, and throughout the total stroke. This research concluded that the wider the stance width, the smaller the COP displacement. The implications of this support previous research and indicate that control of postural stability is a differentiating factor between highly skilled golfers and less skilled amateurs.

While these studies provide some insight into the role of postural stability in putting, their methodologies did not allow for precise assessment of the effects of stability on precise putter kinematics. Recently advancements in the ability to precisely measure and quantify putter kinematics, however, have now made it possible for research to investigate the extent to which COP displacement, weight distribution and other postural stability parameters affect unique aspects in the movement kinematics of the putter.
2.3 Measuring Putter Kinematics in Golf

Previously research into putting kinematics has been limited by the inability to accurately and precisely record the putter’s movements. Without technology to do this, the putting stroke could not be quantified easily, and researchers and teaching professionals alike had to rely on anecdotal means to study and improve the stroke.

With innovations in the instrumentation for recording putting kinematics there is now a precise and accurate method to quantify the movement of the putter. Currently, there are only a small number of commercially available instruments. Notably, the SAM PuttLab system can record all characteristics of the putter movement, including its path, rotation, timing, aim, and dynamics throughout the entire stroke. A reliability study of the SAM Puttlab putter kinematics recording instrument describes it as a high precision ultra-sound instrument designed to track and quantify key kinematic parameters associated with the movement of the putter as a putt is stroked.\(^{25}\) This report stated the results for two series of twenty putts performed by a putting robot that were evaluated with the SAM Puttlab system found the standard deviation of face angle at impact to be 0.1° and 0.09° respectively.\(^{25}\) These results were reported to represent both errors in the measuring instrument and the putting robot used in the study. Thus, the SAM PuttLab system possesses the accuracy, validity and reliability to provide researchers with a powerful tool to investigate the mechanics of the putter and the putting stroke.\(^{25}\)

2.4 Summary

Paramount to this research are previous investigations into balance and its effect on mechanical execution and performance. This research points to a relationship characterized by higher skilled athletes that demonstrate both decreased postural
instability and increased performance. Also, there is relationship that exists between body and foot orientation and COP displacement, and additionally, a relationship between COP displacement and accuracy of performance. To progress the scientific literature, these relationships need to be further investigated.

With previous research linking postural stability to precision athletic performance, and developments in technology that allow for precise, accurate and reliable data collection of putter kinematics, this study investigated the unexplored questions related to postural stability and putter biomechanics.
Chapter 3

3.1 Methods

3.2 Study Design

A crossover study was performed, with randomization of each stance condition (wide, narrow, self-selected) for each subject. Each condition was compared to the other. The investigators were not be blinded to any stance condition.

3.3 Experimental Design

This study consisted of a single testing session. Each subject’s self-selected stance width was measured initially. The independent variables for this study were the three stance conditions (wide, self-selected, narrow). The dependent variables studied were putter kinematics: initial aim (degrees), face angle at impact (degrees), impact spot (mm) and putter path direction through impact. In addition, the dependent variable representing postural stability of mean Medial/Lateral (M/L) COP-X and Anterior/Posterior COP –Y (cm) was measured. These measures were summed to provide a single measure of postural stability, COP-Exy.
3.4 Subjects

Eighteen skilled NCAA Division I amateur collegiate golfers were tested. All student athletes participated in at least five years of competitive golf prior to college golf. Exclusion criteria for the athletes in this research include vestibular disease or having had a concussion within the past month. The University’s Institutional Review Board (IRB) policies on the protection of human subjects were implemented and carefully followed. There was no incentive offered for participation in this study.

3.5 Instrumentation

Testing was conducted on a Players Turf indoor synthetic putting surface (Players Turf Systems, Springfield, IL) at the university’s varsity golf facility. Putter kinematic data were recorded using the SAM PuttLab ultrasound technology system (Science And Motion, Munich, Germany).

Postural sway data for COP was collected by Tekscan F-Scan pressure sensor system (Tekscan, Boston, Massachusetts). The Tekscan F-scan system, in real-time, measures plantar foot pressure via insoles imbedded with pressure sensors. F-Scan Research 6.07 (Tekscan, Boston, Massachusetts) data processing software was used to process the data. ASIS to ASIS measurements were gathered using measurement calipers. Stance width was recorded on a laminated centimeter grid template upon which the subject stood, and hip measurement was taken using a sliding t-square measuring tool.

Data processing was performed with Microsoft Excel (Microsoft Windows 2008, Redmond, Washington). Data analysis was conducted using SPSS 17.0. (SPSS, Chicago, Illinois).
3.6 Procedures

Each session began with measurements of the subject’s hip width (ASIS to ASIS) distance using calipers. Next, the subject’s self-selected stance width was measured. Using the hip width as a base, the wide and narrow stance widths were calculated. Using the centimeter grid template each stance width was marked on the grid and the participant was assigned a random order in which to execute each of the three conditions.

Each subject was then fitted for the F-Scan foot pressure sensor in-soles that were trimmed to size and positioned in the player’s shoes. The F-Scan was tethered to the subjects’ ankle and wires which were connected from the unit to the computer where the data was collected. During testing, the foot pressure data was then recorded in real-time, sampled at 100 Hz, and the resulting data was saved to an external memory device. Processing of the F-scan data included calculation of the center of pressure trajectory of each foot throughout each putt. From these data, mean medial/lateral and anterior/posterior variability of this trajectory was determined. The variability score for each foot was combined to serve as a measure of overall medial/lateral stability (COP-X) and anterior/posterior stability (COP-Y).

Putter kinematic data were measured using the SAM PuttLab system which includes the BasicUnit and the Triplet. The PuttLab BasicUnit, which receives the movement data from the putter, was positioned according to the specifications in the set-up manual. This (Figure 3-1) involved positioning the unit level with the ground twenty centimeters from the ball. To ensure the system was calibrated precisely, the Laser Putter Alignment System (thesmartgolfer, Marblehead, MA) was used in concert with the SAM PuttLab calibration system. The PuttLab Triplet was placed on the subject’s putter shaft.
on the point designated by the set-up manual. During testing, PuttLab data was sampled at 100 hz.

Once the subject was set-up they were allotted several practice trials to become acclimated to the instrumentation in order to proceed normally and comfortably with their putting stroke. After doing so the subject performed twenty 4.6 meter (15 ft) putts, for each of the three stance condition, with their own putter. At the completion of each condition the Players Turf synthetic putting surface was brushed and rolled to maintain consistency of turf conditions. After each trial all postural stability data and putter kinematics data were saved and a new trial began. Each participant performed twenty putts for each condition. From that data the middle ten were analyzed for postural stability measures, putter kinematics, and makes.
Figure 3-1: SAM PuttLab Basic Unit and Triplet
Figure 3-2: Tekscan F-Scan foot pressure insoles
Figure 3-3: Stance condition measurement grid
Figure 3-3: Procedual testing set-up
3.7 Statistical Analyses

A One Way ANOVA was used to compare between group means (i.e. stance width conditions) for the dependent variables related to putter kinematics and postural stability. A Multiple Regression was used to determine to what extent a relationship existed between measures of postural stability and putter kinematics. For all statistical analyses the level of significance was set at P <0.05.

One-Way ANOVA:
1. Mean values for initial aim were compared between the stance conditions.
2. Mean values for impact spot were compared between the stance conditions.
3. Mean values for face angle at impact were compared between the stance conditions.
4. Mean values for putter path direction through impact were compared between the stance conditions.
5. Mean COP-X and COP-Y values were compared between the stance conditions.

Linear Regression with Pearson Correlation:

Multiple Regression:
1. A Multiple Regression was used with the independent (predictor) variables of COP-X and COP-Y for the dependent variable Initial Aim
2. A Multiple Regression was used with the independent (predictor) variables of COP-X and COP-Y for the dependent variable Face Angle
3. A Multiple Regression was used with the independent (predictor) variables of COP-X and COP-Y for the dependent variable Path Direction
4. A Multiple Regression was used with the independent (predictor) variables COP-X and COP-Y for the dependent variable Impact Spot
Chapter 4

4.1 Results

4.3 Directional Putter Kinematics

The One-Way ANOVA tests (Table 4.1) comparing each of the four putter kinematic variables across the three stance conditions revealed no statistically significant differences (p>0.05) for any of these variables.

4.3 Static Postural Stability

There was no statistically significance difference found for either COP-X or COP-Y when compared across stance width conditions (Table 4.1) (p>0.05).

4.4 Putter Performance

There was no statistically significant difference for putts made between the three stance conditions (Table 4.1).

4.5 Regression: Putter Kinematics and Postural Stability

Pearson product-moment correlation coefficient (r) values as well as the coefficient of determination (R Square), for the relationship between the putter kinematic parameters and total static postural stability (COP-E xy), are presented in Table 4.2. The correlation coefficient value (R) is reported and shows the strength and direction of the
relationship between postural stability (IV) and putter kinematics (DV). There was a significant correlation value (R=0.339) for impact spot in relation total COP-E_{xy} (p<0.05). There was a significant correlation value (R=0.336) for putter path direction through impact in relation to COP-E_{xy} (p<0.05). There was a significant correlation value (R=0.441) for putter path direction through impact in relation to total COP-E_{xy} (p<0.05). There was no significant correlation value (R=0.115) for initial aim in relation to total COP-E_{xy} (p<0.05; Table 4.2). The coefficient of determination value (R Square) for impact spot was 0.115, 0.113 for face angle, 0.195 for putter path direction through impact and 0.013 for initial aim.

The standardized correlation coefficient (Beta) and the 95% confidence intervals for Beta are reported for the relationship between putter kinematics and A/P COP-X and M/L COP-X respectively. Here the total COP-E_{xy} has been partitioned into two separate measures and their individual Betas are reported. For impact spot the COP-Y Beta was not significant at 0.324, 95% C.I. (0.163, 2.037) and the COP-X Beta was significant at 0.229, 95% C.I. (-15.674, 1.456) (p<0.05). For face angle at impact COP-Y Beta was significant at 0.108, 95% CI (-0.196, 0.447) and COP-X was not significant at 0.351, 95% CI (-6.669, -0.79) (p<0.05). For putter path direction the COP-Y Beta was 0.315, 95% C.I. (-0.674, -0.06) and COP-X Beta was 0.413, 95% C.I. (1.598, 7.215) both of which are statistically significant (p<0.05). For initial aim the COP-Y Beta was 0.025, 95% C.I. (-0.203, 0.171) and COP-X Beta was 0.106, 95% C.I. (-2.326, 1.09) neither values were statistically significant (p<0.05).
4.6 Prediction Model: Putter Kinematics

From the multiple regression analysis a model was developed for each of the putter kinematic variables ($\hat{y}=a+Bx+By$). The linear least-squares regression analysis for impact spot yielded the model equation of $\hat{y}= 3.997 + 7.109(COP-X) + 1.100(COP-Y)$ (Figure 4-1). The linear least-squares regression analysis for face angle at impact yielded the model equation of $\hat{y}= 1.967 + 3.370(COP-X) + 0.126(COP-Y)$. The linear least-squares regression analysis for putter path direction yielded the model equation of $\hat{y}= 1.453 + 4.406(COP-X) + 0.367(COP-Y)$ (Figure 4-3). The linear least-squares regression analysis for initial aim yielded the model equation of $\hat{y}= 1.131 + 0.0618(COP-X) + 0.016(COP-Y)$ (Figure 4-4).

4.7 Base of Support

Table 4.4 presents descriptive statistics of stance widths for each stance condition. This data is expressed as a percentage of the players ASIS-to-ASIS measurement. The mean wide stance was 1.476±0.255 percent, the mean self selected stance was 1.003±0.255 percent and the narrow stance mean was 0.515±0.257. Each of these mean values were significantly different for the other stance conditions (p<0.05)
Table 4.1: Descriptive statistics for putter kinematics, postural stability and putts made and stance condition (n=18, p<0.05).

|                        | Mean   | Standard Deviation | 95% Confidence Interval for Mean |  |  |
|------------------------|--------|--------------------|----------------------------------|  |  |
|                        | Lower Bound | Upper Bound | F     | Sig. |
| FaceAngle              |         |                   |       |     |
| Narrow                 | 1.410  | 0.717             | 1.053 | 1.767 |
|                        | 1.212  | 0.968             | 0.730 | 1.693 |
|                        | 1.686  | 1.01              | 1.182 | 2.189 |
| Self Selected          |         |                   |       |     |
| Wide                   | 1.237  | 0.299             |       |     |
| PathDirection          |         |                   |       |     |
| Narrow                 | 1.681  | 1.01              | 1.177 | 2.185 |
|                        | 1.757  | 0.811             | 1.353 | 2.160 |
|                        | 1.706  | 0.960             | 1.228 | 2.184 |
| Self Selected          |         |                   |       |     |
| Wide                   | 1.237  | 0.299             |       |     |
| ImpactSpot             |         |                   |       |     |
| Narrow                 | 4.501  | 2.37              | 3.322 | 5.680 |
|                        | 4.297  | 2.82              | 2.896 | 5.697 |
|                        | 4.469  | 2.92              | 3.018 | 5.920 |
| Self Selected          |         |                   |       |     |
| Wide                   | 1.237  | 0.299             |       |     |
| Aim                    |         |                   |       |     |
| Narrow                 | 0.969  | 0.391             | 0.774 | 1.164 |
|                        | 0.885  | 0.552             | 0.610 | 1.160 |
|                        | 1.088  | 0.554             | 0.812 | 1.364 |
| Self Selected          |         |                   |       |     |
| Wide                   |         |                   |       |     |
| COP-Y                  |         |                   |       |     |
| Narrow                 | 1.785  | 0.907             | 1.333 | 2.236 |
|                        | 1.636  | 0.592             | 1.342 | 1.931 |
|                        | 1.586  | 0.850             | 1.164 | 2.009 |
| Self Selected          |         |                   |       |     |
| Wide                   |         |                   |       |     |
| COP-X                  |         |                   |       |     |
| Narrow                 | 0.213  | 0.099             | 0.164 | 0.263 |
|                        | 0.198  | 0.082             | 0.157 | 0.240 |
|                        | 0.183  | 0.075             | 0.145 | 0.220 |
| Self Selected          |         |                   |       |     |
| Wide                   |         |                   |       |     |
| Putts Made             |         |                   |       |     |
| Narrow                 | 4.11   | 2.272             | 2.981 | 5.241 |
|                        | 4.66   | 2.990             | 3.179 | 6.153 |
|                        | 4.50   | 1.504             | 3.751 | 5.248 |
| Self Selected          |         |                   |       |     |
| Wide                   |         |                   |       |     |
|                        | 1.237  | 0.299             |       |     |

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Note: Units for Face Angle, Path Direction, and Aim are degrees of deviation from the target line. Units for Impact Spot are millimeters of deviation from the center of the putter face. Units for COP –Y and COP –X are centimeters of variation around the mean A/P and M/L COP path. Units for Putts made are makes out of 10 trials.

Table 4.2: Regression Model. Correlation (r) values and coefficient of determination (R Square) values for the relationship between putter kinematics and measures of postural stability (n=54, p<0.05).

<table>
<thead>
<tr>
<th>Model</th>
<th>r</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Impact Spot)</td>
<td>0.339*</td>
<td>0.115</td>
<td>0.08</td>
<td>0.045</td>
</tr>
<tr>
<td>2 (Face Angle)</td>
<td>0.336*</td>
<td>0.113</td>
<td>0.078</td>
<td>0.047</td>
</tr>
<tr>
<td>3 (Path Direction)</td>
<td>0.441**</td>
<td>0.195</td>
<td>0.163</td>
<td>0.004</td>
</tr>
<tr>
<td>4 (Initial Aim)</td>
<td>0.115</td>
<td>0.013</td>
<td>-0.025</td>
<td>0.711</td>
</tr>
</tbody>
</table>

Predictors: COP-X, COP-Y
*Regressions Prediction Relationship is significant at the .05 level
**Regressions Prediction Relationship is significant at the .01 level
Table 4.3 Linear Multiple Regression: Standardized correlation coefficients (Beta) with 95% Confidence Intervals for the relationship between putter kinematics and A/P COP-X and M/L COP

<table>
<thead>
<tr>
<th>Model</th>
<th>Standardized Coefficients</th>
<th>95.0% Confidence Interval for B</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta</td>
<td>Lower Bound</td>
<td>Upper Bound</td>
</tr>
<tr>
<td>1 Impact Spot</td>
<td>(Constant)</td>
<td>1.926</td>
<td>6.069</td>
</tr>
<tr>
<td></td>
<td>COP-Y</td>
<td>0.324</td>
<td>0.163</td>
</tr>
<tr>
<td></td>
<td>COP-X</td>
<td>0.229</td>
<td>-15.674</td>
</tr>
<tr>
<td>2 Face Angle</td>
<td>(Constant)</td>
<td>1.256</td>
<td>2.678</td>
</tr>
<tr>
<td></td>
<td>COP-Y</td>
<td>0.108</td>
<td>-0.196</td>
</tr>
<tr>
<td></td>
<td>COP-X</td>
<td>0.351</td>
<td>-6.669</td>
</tr>
<tr>
<td>3 Path Direction</td>
<td>(Constant)</td>
<td>0.774</td>
<td>2.132</td>
</tr>
<tr>
<td></td>
<td>COP-Y</td>
<td>0.315</td>
<td>-0.674</td>
</tr>
<tr>
<td></td>
<td>COP-X</td>
<td>0.413</td>
<td>1.598</td>
</tr>
<tr>
<td>4 Aim</td>
<td>(Constant)</td>
<td>0.718</td>
<td>1.544</td>
</tr>
<tr>
<td></td>
<td>COP-Y</td>
<td>0.025</td>
<td>-0.203</td>
</tr>
<tr>
<td></td>
<td>COP-X</td>
<td>0.106</td>
<td>-2.326</td>
</tr>
</tbody>
</table>
Table 4.4 Mean stance width expressed as a percent of player ASIS-to-ASIS for each stance condition (±SD, n=18).

<table>
<thead>
<tr>
<th>Stance Width</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide</td>
<td>34.3</td>
<td>6.22</td>
<td>.000</td>
</tr>
<tr>
<td>Self Selected</td>
<td>23.0</td>
<td>6.03</td>
<td>.000</td>
</tr>
<tr>
<td>Narrow</td>
<td>11.7</td>
<td>5.98</td>
<td>.000</td>
</tr>
</tbody>
</table>
\[ \hat{y} = 3.997 + 7.109(COP-X) + 1.100(COP-Y) \]

Figure 4-5: Least-Squares analysis for Impact Spot and Total COP-X (A/P & M/L).
\[
\hat{y} = 1.967 + 3.370(\text{COP-X}) + 0.126(\text{COP-Y})
\]

Figure 4-6: Figure 4-1: Least-Squares analysis for Face Angle and Total COP-X (A/P & M/L)
\[ \hat{y} = 1.453 + 4.406(COP-X) + 0.367(COP-Y) \]

Figure 4-7: Least-Squares analysis for Putter Path Direction through impact and Total COP-X (A/P & M/L).
\[ \hat{y} = 1.131 + 0.0618(COP-X) + 0.016(COP-Y) \]

Figure 4-8: Least-Squares analysis for Initial Aim and Total COP-X (A/P & M/L).
Table 4.5: Pearson Product-Moment Correlation Coefficient Scale

<table>
<thead>
<tr>
<th>R Value</th>
<th>Strength of relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 to 0.5</td>
<td>Strong</td>
</tr>
<tr>
<td>0.3 to 0.5</td>
<td>Moderate</td>
</tr>
<tr>
<td>0.1 to 0.3</td>
<td>Weak</td>
</tr>
<tr>
<td>−0.1 to 0.1</td>
<td>None or very weak</td>
</tr>
</tbody>
</table>
Chapter 5

5.1 Discussion

The purpose of this study was to examine the influence of base of support characteristics on static postural stability as well as postural stabilities influence on the putter kinematics associated with directional control. Previous research examining static postural stability have linked it to performance in archery, similar research has linked ability level in rifle shooting to COF movement. Also, rifle shooting accuracy was related to postural stability. The current research first compared how changing the base of support impacted the putter kinematics of interest. Prior research in pistol shooting found decreases in aim and postural stability when stance width was increased, these findings were not consistent with those found in this study. The investigation also studied base of support characteristics to compare how changing stance width influenced static postural stability. Finally, relationships between postural stability and putting kinematics were considered. Previous research studying elite rifle shooters found performance decreases associated with increases in COP displacement, these findings are in agreement with the findings of this investigation.

The research examined the relationship between static postural stability and putter kinematics. This was done by measuring COP displacement for each of three stance
conditions with an insole foot pressure system, as a measure of static postural stability, and comparing this measure across four separate putter kinematic parameters. It was hypothesized that 1) the wide stance condition would have significantly lower (better) overall mean score for each of the putting parameters, followed by that of the self selected condition, and finally that of the narrow condition, 2) the wide stance condition would produce significantly lower total COP displacement compared to the self-selected and narrow stances throughout the putting stroke, 3) a decreased total COP displacement would correspond to significantly lower mean scores for each of the key putting parameters. Some of these hypotheses proved correct and provide insights into the relationship between static postural stability and directional putter kinematic parameters.

5.2 Putter Kinematics and Base of Support

For the measures of impact spot, face angle at impact, putter path direction through impact and initial aim the ANOVA revealed that there was no statistically significant difference across the three stance conditions (Table 4.1). Thus, this analysis does not support the hypothesis that putter kinematics would be influenced by stance width. However, for three of the four putter kinematic variables (face angle at impact, putter impact spot and initial aim), interestingly, the self selected stance condition appeared to yield the lowest mean values. Considering the wide stance condition, for the kinematics of initial aim, putter path direction through impact and putter impact spot, this stance condition yielded the highest mean values. As high mean scores reflect sub-optimal putting kinematics, lower mean values for the kinematics in the self selected
condition, although not significant, suggest that the players self selected stance resulted in more biomechanically optimal putter kinematics.

While these differences were not statistically significant, they indicate an interesting trend that suggests that elite collegiate golfers evolve towards a putting stance (their self selected stance) that produces optimal putting kinematics. Why the wide stance failed to produce better results, even though it would appear to have the potential to produce the greatest postural stability, is a matter of speculation. Our finding are somewhat consistent with a previous shooting study by Hawkins\textsuperscript{12} that demonstrated that a more narrow stance actually yielded better aim than a wider stance. However, no other previous research has shown stance width to be related to optimization of kinematics (other than aim) in a task like putting. Cognizant of this finding, reasons for the unexplained differences can still be considered.

Some of these differences may be a result of this population’s extensive putting experience and an associated acclimation to their usual stance width. It would be uncommon for an elite player to alter their putting stance width, and it is likely that requiring them to do so to the magnitude of ±50% of their hip width would put them into an unfamiliar stance position. Although a wider stance width would seem to have the potential to improve stability, either a wider or narrower stance width would correspond to changes in the player’s orientation to the ball including ball position. This, in turn, may also change the player’s perception and ‘feel’. This may explain why three of the four putting kinematics were more biomechanically appropriate at the self-selected unchanged stance condition.
5.3 Putting Performance

Considering the potential influence of stance width on all of the kinematic variables, it was hypothesized that stance width would influence the ultimate outcome of these kinematics, the frequency of making putts. When it came to putting outcomes (makes/misses) the results appeared to show that the self selected condition had the most average makes, followed by the wide stance condition and the narrow stance condition (Table 4.1). However, as with the specific kinematic variables, the differences seen here were not statistically significant. This is somewhat surprising, as it was anticipated that the link between stance width and postural stability would be reflected in the ability of the subjects to make putts. Similar findings between postural sway and putt outcome showed postural sway was similar for both made and missed putts.²

Since no difference was shown in makes considering stance condition it may be an indication that factors other than putter kinematics are significant determinants of putting accuracy. It is widely accepted that putting outcome is impacted by parameters other than the stroke mechanics, such as green inconsistencies, green speed, ball velocity (speed) and proper green reading putt. Simply stated you can make a mechanically optimal putting stroke and one of the other outcome parameters can cause the putt to miss its mark. This may have been the case in the present study. Although the synthetic putting surface was swept and rolled between conditions in order to ensure the consistency of the surface, there was an observable influence of the surface on ball direction. Similarly, other factors that may have influenced the putt outcome were the pace of the putt, deflection of the ball off its line by a surface irregularity, or a miss read of the break of the putt.
5.4 Static Postural Stability and Base of Support

Examining the measures of postural stability of A/P and M/L COP the results show the mean values for the wide condition were the smallest followed by the self selected condition and the narrow condition (Table 4.1). Lower mean values for A/P and M/L COP are representative of greater static postural stability. However, the differences that were observed were not statistically significant. Thus, the hypothesis in regards to how postural stability compares across the stance condition was not supported. The trend indicated by these finding, however, although not significant, is what our investigation had expected to find, as it was hypothesized that increased stance width would result in increased stability. It is well established that an increase in stance width increases the potential for creating an external stabilizing torque, while a decrease in stance width does the opposite. Similar findings have been seen in the scientific literature with regard to base of support and postural stability.\textsuperscript{13, 14, 20, 2, 31} Each of which reported a decreased base of support was associated with decreases in measures of postural stability or emphasized the importance of base of support for static postural stability. Although the results tended to follow this principle, the differences between the conditions were not as great as had been expected.

In a previous study on putting, Hurion\textsuperscript{16} found that for a twenty five foot putt amateurs demonstrated 83.10 millimeters of mean total body sway and for professional’s 64.34 millimeters. Thus, professionals were more stable during putting than the amateurs. As it is assumed that the professionals were better putters than the amateurs, the implication is that there is a link between stability and putting accuracy. That this was not more apparent in the present study is somewhat surprising.
One possible explanation may have to do with the length of the putt. This study examined a flat 15 foot putt whereas Hurion studied a twenty five foot putt. A longer stroke would likely be required to produce enough force to reach the target, causing a greater perturbation, influencing postural stability. Thus, as putt length increases the role of stability may be increasingly important. This observed difference from Hurrion could also be linked to how COP displacement was calculated rather than a difference in the respective samples. In this investigation, mean total COP for both A/P and M/L were combined to determine this value. In Hurrion’s study actual displacement, as calculated by data from a center of pressure. It may be that this method is a more sensitive measure of stability, and thus better able to discriminate the effects of variations in stance width. Regardless, although the trend of the data was consistent with what was hypothesized, this hypothesis was not supported.

5.5 Static Postural Stability and Putter Kinematics

A linear multiple regression with a Pearsons correlation was performed investigating the relationship between measures of static postural stability and putter kinematics (Table 4-2). Static postural stability was measured by combining A/P and M/L COP to determine total COP for the regression. Three of the four putter kinematic variables showed a significant and positive relationship bordering in strength between moderate and weak as determined by the Pearson Product-Moment Correlation Coefficient Scale (Table 4.5). Understanding that these relationships are significant however are only moderate in strength, this limits the interpretations that can be made. The results are consistent with a similar study on archery performance and static postural
stability. They found that with archery, COP displacement had a strong relationship to performance also.

The strongest positive relationship was found between putter path direction and total COP followed by impact spot and face angle at impact. These findings support the original hypothesis that decreases in COP-E_xy will be associated with lower (better) mean values for putter kinematics. Initial aim showed none or a very weak, non-significant positive relationship. This finding is not consistent with the corresponding hypothesis. The nature of this weak positive relationship may be due to the fact that aim was measured at the beginning of the putting stroke while COP-E_xy was measured throughout the putting stroke. Thus, it may be that a time-wise segmentation of COP-E_xy partitioning it into an ‘initial’ phase would yield a different relationship than the one found here.

The findings that were significant are of interest when looking at previous research. Putter path through impact, impact spot and face angle at impact kinematics were found to account for all of the directional consistency of the putt. That finding combined with this investigation’s finding that each of these kinematic parameters were moderately and significantly related to COP-E_xy indicates that as the players static stability increases there is a concurrent improvement in putter kinematics, although these measures are only moderately related. The moderate strength of the association found between these measures dictate that the interpretations drawn here should not be overstated in their implications.

Table 4.2 also yields the coefficient of determination (R Square) a value that represents the amount of response variation or variation in the putter kinematics that is
explained by the predictor variables (COP-Y and COP-X) for each model. The coefficient of determination for impact spot was 0.115, which means 11.5% of variation in impact spot can be accounted for by COP-E_{xy}. For face angle at impact this value was 0.113, where 11.3% of variation in face angle at impact can be explained by COP-E_{xy}. For path direction at impact the value was 0.195 where 19.5% of variability in putter path direction at impact can be attributed to COP-E_{xy} and for initial aim 1.3% of variability could be attributed to COP-E_{xy}. These findings show that these measures of postural stability account for a relatively small portion of variation in putter kinematics. However, due to the precise nature of putting this small variability in kinematics due to postural control could make a difference since the margins in putting are small.

Comparing these results to those similar results in an investigation of rifling performance and postural stability where 22-40% of performance and 20-74% of aiming fluctuation could be predicted by body sway\(^7\), respectively it is seen that postural stability is not as great a predictor of performance in putting as it is for rifling. An explanation of the difference in these results may be that in activities such as archery, rifle and pistol shooting there is a lack in the degree of perturbation required to propel the object at its target. Due to this greater perturbation inherent to putting, variation in kinematics may be more dependent on neural control and communication between the cerebral motor cortex and the sensorimotor structures located in the joints of the arm, wrist and hand.\(^2\)

5.6 Prediction Model
Regression scatter plot data and the formulated model equation for the DV impact spot and in relation to the predictor of COP-E_{xy} was reported (Figure 4-1). For a given COP-E_{xy} value this predictive model will output a predicted impact spot value. Given that the model’s coefficient of determination is somewhat low, (R Square 0.115) COP-E_{xy} accounts for 11.5% of the variation in impact spot based. Figures 4-2 and 4-3 offer the same regression data and model equations for the DV’s face angle, putter path and initial aim respectively. Similar to impact spot, the R-Square value showed that 11.3% of variability in face angle could be accounted for by COP-E_{xy}. For putter path direction 19.5% of variability here could be attributed to COP-E_{xy}. Considering the relatively small impact COP-E_{xy} has on putter kinematics, further investigation into player kinematic factors that affect stroke mechanics and putter mechanics is needed to account for the variation that remains.

In the linear multiple regression analysis when COP-E_{xy} was partitioned into COP-Y and COP-X the corresponding Beta values provide the correlations between each of the two partitioned predictors and the dependent variables, controlling for the other predictor (Table 4-3). For impact spot COP-Y had a stronger predictive relationship (β=0.324) than COP-X (β=0.229), although COP-X was statistically significant and COP-Y was not. One possible explanation for COP-Y having a stronger predictive associated with impact spot may be due to the manner impact spot is measured and how anterior/posterior movement by the player may be associated with this measure.

The impact spot is a measure of the horizontal distance (mm) from the midline of the putter in which the putter makes contact with the ball. COP-Y movement of the player would indicate heel to toe movement of the player’s center of gravity. Heel to toe
movement would shift the player’s orientation to the ball where he/she would be closer/further in relation to the ball which is likely to affect the horizontal impact spot of the ball on the putter. COP-X has a weaker yet statistically significant association with impact spot.

This relationship may be weaker because M/L movement may not likely account for a change in player orientation to the ball where he/she was closer to the ball. Still, with COP-X having a significant relationship when controlling for COP-Y indicates that M/L displacement is a moderately strong predictor for impact spot. The implication for this measure as well as with the COP-Y measure is that solid contact between the ball and the club can be moderately predicted by these measures and controlling these measures may translate into more control of impact spot.

Considering putter path direction and face angle at impact COP-X had a stronger predictive relationship than COP-Y for both kinematic variables. The kinematic of path direction showed that both COP-X ($\beta=0.413$) and COP-Y ($\beta=0.315$) were significant moderate predictors (Table 4-3). The predictive relationship here may be a function of COP-Y which indicates heel to toe movement of the player. This movement possibly predicts this kinematic by influencing player orientation where the players upper torso either moves closer to or further from the ball which predicts deviation in putter path from the target.

COP-X had a greater moderate predictive association than COP-Y. This relationship indicates that COP-X is a slightly stronger predictor of path direction. This predictive relationship may be attributed to the nature of this kinematic measure. Putter
path is a measure of the angle the putter path is directed in relation to the target ten centimeters prior to and post ball impact. The twenty centimeters is a truncation of the entire putting movement. The putter movement can be characterized primarily by movement in the frontal plane which is a result of the frontal plane movement of the shoulders (abduction/adduction). This movement causes primary linear displacement of the putter in the frontal plane.

Relating this to COP-X, which would be associated with the player’s movement along the frontal plane and is associated with M/L sway, the predictive relationship between COP-X and putter path direction is clearer. When putter path is not optimally directed COP-X moderately and significantly predicts this kinematic, and controlling COP-X may likely predict more control of putter path. This finding may be of greater importance when considering longer length putts. Here the perturbation of the putter movement is larger which is likely associated with greater COP-X displacement and since this measure moderately predicts control of putter path limiting COP-X may predict improved putter path. Interestingly, a 2008 study of expert golfers head movement through the putting stroke showed head movement in expert golfers that was in the opposite direction of the stroke. This is a possible mechanism that reduces the putting strokes perturbation on postural stability and decreases both COP-X and COP-Y.

The Beta values for COP-X (β=0.351) and COP-Y (β=0.108) for face angle were similar to those found with the kinematic variable of putter path where the Beta COP-X indicated a stronger predictive relationship than COP-Y. The difference in this predictive model is COP-Y yielded a significant predictive relationship and COP-X did not. This shows that COP-Y has a small, significant predictive relationship and COP-X has a
moderate, not significant predictive relationship while COP-Y has significant small predictive relationship. The mechanisms behind these findings are unclear, but they tell us that M/L displacement moderately predicts face angle while A/P displacement is a small significant predictor. This implicates that controlling displacement may predict control the putter face orientation at impact leading to better directional control.

Collectively these findings indicate that measures of postural stability account for a relatively small amount of the variability in directional putter kinematics. Also they show that postural stability is generally a moderate and sometimes significant predictor of directional putter kinematics. Mechanisms for these predictive relationships have been speculated but without further investigation they remain relatively unknown.

5.7 Base of Support

Provided in Table 4.4 are the stance widths for each condition as a percentage of the players anatomical hip width measured from ASIS-to-ASIS. As would be expected the wide stance condition employed a stance width that was greater than the other two stance conditions and the self selected condition used a stance width greater than the narrow condition. The width of each stance significantly differed across the stance conditions. Applying this information practically along with the previous data that shows both the narrow and wide stance conditions being related to less optimal putter kinematics, it may prove beneficial from an instruction perspective, to ensure that the stance width recommended for putting tends to match the golfers anatomical hip width. Another manner these results could be incorporated into golf instruction is when the player uses a narrower stance. In such a case instruction encouraging the player to use a stance width slightly wider than what they would naturally assume, and over time this set
up position would become what the player feels is normal. This may take advantage of the decrease in COP displacement and because the player could acclimate themselves to the set-up, putter kinematics may be elevated from those seen during their natural stance. This application is speculative, requiring further investigation.

5.8 Limitations

The results of this study of putting and static balance were derived from a controlled environment characterized by consistency; where the ground was level and firm, the putt length was unchanged and the break characteristics of the green remained constant. This environment was unlike the conditions faced during a round of golf. Golf by nature is a game played in constantly changing environments, where each putt presents the player with a new set of factors to negotiate. Factors such as green slope, ground conditions, putt length and even wind conditions can affect the static stability of the player. That these differences in condition could not be simulated during testing, serves as a limitation on this study. Also, this study was limited by failing to control for shoe type, which depending on the characteristics of the shoe, could potentially alter the player’s center of pressure characteristics.

5.9 Practical Relevance

In the sample of golfers studied in this investigation the effects of the independent variables may have been less obvious that they would have been on a less skilled population. The COP values from our sample of elite collegiate golfers were small in magnitude, characterizing their postural stability as very consistent. This characteristic is a probable result of the constant, repetitive practice for sustained durations that is typical of elite golfers and the length of putt in this study. A population of recreational golfers
may likely not exhibit the stability that this sample showed, and as a result the independent variables in question may have a much more pronounced effect.

The implications of this finding may be of greater significance to a less skilled golfing population whose practice habits are not equivalent and whose putting technique and mechanics are deficient compared to the sample in this study. They may also be more significant to putts of longer length. The implications of the findings of this study may also prove more relevant to the conditions faced by players during a round, where environmental factors are subject to change, which could influence the player’s ability to maintain consistent postural stability during the putting stroke.

5.10 Conclusion

This study was able to find significant, yet only moderate correlation between total COP and putter kinematics associated with putting accuracy, where greater postural stability was moderately associated with better putter kinematics. This study was also able to show a trend indicating that mean total COP decreased as the base of support was increased, although this finding was not statistically significant. The study found that skilled collegiate golfers displayed biomechanically more optimal putter kinematics when using their self selected stance and had the least biomechanically optimal putter kinematics with a wide stance. This final finding seems to contradict the trends shown in the first two findings and, for this population, limits the link that can be drawn between postural stability and putter kinematics. Similar investigation of less skilled populations is needed which may be helpful in revealing the relationship between stance, postural control and putting mechanics.
References


30. WALLACE, E., GRAHAM, D., & BLEAKLEY-EW. (1990). Foot-to-ground pressure patterns during the golf drive ; a case study involving a low handicap player and a high handicap player (Styles d'appui au sol pendant le drive ; une etude de cas concernant le joueur de faible handicap et le joueur de haut handicap). In , Science and golf ; proceedings of the first world scientific congress of golf, St Andrews,Scotland, 9-13 th July 1990 E et FN Spon, London, New-York, Tokyo ROYAUME UNI/ETATS-UNIS D'AMERIQUE/JAPON 1990, pp 25-29