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The effect of movement variability on putting proficiency during the golf putting stroke

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KEYWORDS: golf putting, variability, performance, kinematics, dynamical systems, golf coaching

Abstract

Movement variability has been considered important to execute an effective golf swing yet is comparatively unexplored regarding the golf putt. Movement variability could potentially be important considering the small margins of error between a successful and a missed putt. The aim of this study was to assess whether variability of body segment rotations influence putting performance (ball kinematic measures). Eight golfers (handicap range 0 – 10) performed a 3.2 metre level putt wearing retro-reflective markers which were tracked using a three-dimensional motion analysis system sampling at 120 Hz. Ball roll kinematics were recorded using Quintic Ball Roll launch monitor. Movement (segment) variability was calculated based on a scalene ellipsoid volume concept and correlated with the coefficient of variation of ball kinematics. Statistical analysis showed no significant relationships between segment variability and putting proficiency. One significant relationship was identified between left forearm variability and horizontal launch angle but this did not result in deficits in putting success. Results show that performance variability in the backswing and downswing is not related to putting proficiency or the majority of ball roll measures. Differing strategies may exist where certain golfers may have more fluid movement patterns thereby effectively utilising variability of movement. Therefore, golf instructors should consider movement variability when coaching the golf putt.

Introduction

The putting stroke accounted for 41% of all strokes during tournaments on the Professional Golf Association (PGA) Tour in 2014. [1,2] Additionally putting is a key determinate of earnings on the PGA Tour. [3,4] Recently movement variability has been identified as an important biomechanical principle to research. [5–7] Currently to date research of movement variability in the golf putt is scarce with more research needed in the area to establish its effect on performance. [8] Movement variability has been stated as important for successful performance and technique during the golf swing. [5,9] Considering similar performance goals for golf putting movement variability may also be important for this aspect of golf.

As outlined in dynamical systems theory, movement patterns arise, mature and develop from synergistic organisation of the neuromuscular system adapting to environmental factors exposed to, morphological factors and task constraints. [10] Different movement patterns will develop between individuals with a unique set of different constraints, allowing for different techniques to achieve the same performance outcome. [11,12] With the golf swing being a complex and high velocity technique the existence of an invariant movement pattern is unlikely. [5] Inter and intra-individual differences may also be apparent for the golf putt, due to the smaller margins of error between a successful or missed shot. [13,14] The consensus amongst the literature with the full golf swing in regard to movement variability is to reduce variability at key swing events for successful performance. [9,15,16]

The authors however consider using a time-continuous data set for the calculation of variability preferable to observing variability at specific points. [7] This is because the golf swing or putting stroke is a continuous skill and doesn't occur only at discrete points, therefore it is more applicable to observe variability across the full movement. When variability across the golf swing from the start of the movement to impact was considered in the full golf swing, no relationship with an outcome measure (initial velocity of the golf ball) was identified. [5] A limitation of the aforementioned study was ball direction or accuracy was not considered a performance measure. Movement variability will likely affect the swing trajectories and club head angle at impact (affecting shot direction) as well as the speed of movement (affecting the ball flight velocity). Club head angle at impact has previously shown variability for the golf swing and golf putt. [13,14,17]

During putting it has been established that factors accounting for direction consistency/variability – putter face angle (80 – 83%), the trajectory of the putter path (17%) and horizontal impact point on the putter face (3%). [14,18] In principle if these task criterion factors remain consistent with a low variability the initial launch angle of the golf ball will remain consistent resulting in more putts that are successful. When considering technique it should matter little as to whether a consistent technique with low variability, or coordinated variability of body movement is utilised to achieve this. Therefore, emphasis always being placed on a low variability movement may be incorrect when considered from a dynamical systems approach and different strategies including variable body movement patterns may be integral to successful putting performance. [5,19]

Movement variability for some may be a key determining factor to the reduction in variance of the task criterion putter face angle at impact and therefore performance. Coaching and golf putting instruction manuals traditionally has focused on encouraging techniques aiming to achieve low variability, where a linear stroke is desired. [18] Scientific literature has however outlined this is biomechanically complicated and difficult with reliance on compensatory muscle activity keeping the putter face square whilst the body rotates. [14] This therefore may not be the best technique for golfers to adopt or coaches to teach.

The aim of this study was to assess whether the variability of body segment rotations and putter rotations influence the variance of performance measures (ball roll kinematics: velocity, side spin, initial ball roll, forward rotation, vertical launch angle and horizontal launch angle). It was hypothesised that significant relationships would exist between the variability of body segments and performance measures.

Methods

Participants

A total of 8 right-handed golfers participated in the study (age 34 ± 11 years; handicap 6.0 ± 3.4 (handicap range 0 – 10); height 1.80 ± 0.06 metres; mass 83.4 ± 12.2 kg). All golfers were free of musculoskeletal injury for a minimum period of 3 months and played a minimum of once a week. During testing participants wore their own personal golfing attire and suitable dark, tight fitting non-reflective shorts and short sleeved top. All participants provided written informed consent and the study was approved by the institutional ethics committee of University of Hertfordshire.

Experimental set-up

Testing was completed on a Huxley Golf (Huxley Golf., Hampshire, UK) artificial putting green (3.66 x 4.27 metres) registering 11 on the stimpmeter (The United States Golf

Association., Far Hills, NJ, USA). A level, straight 3.2 metre putt was setup thus minimising the effect of green reading and aim with a regulation 108 mm hole. [14,20] Participants used their own personal putter for the protocol. The rationale for this was the participant would be using a putter they were already habituated to. This ensured the body movement kinematics were a true reflection of their technique, whereas a standardised putter not fitted to each of the participants could negatively influence this. The golf ball for the protocol were Srixon Z-STAR (Srixon Sports Europe LTD., Hampshire, UK) and each trial completed used the same ball. Body movement kinematics were recorded using a ten camera motion analysis system (Motion Analysis Corporation., Santa Rosa, CA, USA) sampling at 120 Hz.

Retro-reflective markers were attached to participants in accordance with a modified whole body Helen Hayes marker set (total 31 markers; 14 mm) at the following anatomical locations: top of head, front of head, rear head, acromion process (left and right), lateral epicondyle of humerus (left and right), styloid process of the radius (left and right), on the forearm intersecting the humeral epicondyle and styloid process of the radius (left and right), anterior superior iliac spine (left and right), the sacrum, the thigh (intersecting the plane between the hip and knee markers (left and right)), lateral aspect of the joint centre of the knee (left and right), the shank (intersecting the plane between the knee and ankle markers (left and right)), the lateral malleolus (left and right), the posterior aspect of the calcaneus (left and right) and the third metatarsal (left and right). Markers were placed directly on the skin using double sided tape, except the acromion process (pair of), anterior superior iliac spine (pair of), sacrum, calcaneus (pair of) and third metatarsal (pair of) which were placed on skin tight 'under-armour' clothing or shoes ensuring minimal movement of markers relative to underlying body landmarks. Additionally, a marker was placed on the left scapula for asymmetry and medial aspects of the knee (left and right) and medial malleolus (left and right) so the joint centres of the knee and ankle could be calculated.

Two retro-reflective markers were placed on the superior aspect of the putter face to calculate putter face angle at impact and throughout the putting stroke. A retro-reflective marker was also placed on the putting line. The capture volume was calibrated according to manufacturer's guidelines, resulting in an average residual for all cameras of < 0.2 mm. The motion analysis system was calibrated where the positive movement along the X-axis was defined as movement towards the target (golf hole); positive movement along the Y-axis was defined as movement anteriorly perpendicular to the target; and the Z-axis perpendicular to the X, Y plane.

To record the ball roll kinematics, a Quintic (Quintic Consultancy Ltd., Coventry, UK) high speed camera (UI-5220RE) sampling at 220 Hz was positioned perpendicular to the putting line. The Quintic v2.4 launch monitor software was used to analyse the recorded ball roll. Kinematic variables analysed were initial velocity ($m \cdot s^{-1}$, calculated across the first 6 recorded frames), side spin (the amount of side spin (rpm) placed on the ball during impact), vertical (whether the ball was launched in the air) and horizontal (the degree to which the ball deviates from the original putting line) launch angle (º), initial ball roll (whether the ball has positive rotation (topspin) or negative rotation (backspin) at the point of impact (rpm)) and forward roll (the distance at which the ball starts positive rotation (cm)). For a trial to be considered valid, the initial ball velocity had to be between 2.10 – 2.28 $m \cdot s^{-1}$. This was to eliminate participants' preference of either putting to hole the ball successfully at very low or high velocities which could alter movement variability observed. Putts that did not meet the initial ball velocity requirements were eliminated from analysis. Despite this only one putt was eliminated from analysis.

Procedure

Participants were allowed up to ten minutes to habituate themselves to the golf putt, to ensure that the markers did not inhibit or alter their technique. Within the ten minute habituation period, the investigator instructed the participant as to the velocity required for a putt to be categorised successful. Once the participant was comfortable and ready to proceed, they lined up the golf putt and approached the putt. The 3D motion analysis system recorded the trial and the outcome of the putt was recorded (successful or missed). This process was completed until 10 successful putts had been completed with time between each trial for the participant to reline up the putt. All putts (successful and unsuccessful) were included for analysis.

Data Processing

Three-dimensional coordinate data were processed using Cortex (Motion Analysis Corportation; Santa Rosa, CA, USA) software with an Euler sequence of X, Y, Z. The 3D coordinate data were filtered using a fourth-order low pass Butterworth filter, consistent with previously published literature. [16,21,22] Cut off frequency was determined using residual analysis with an r^2 threshold of 0.85. [23] Cut off frequencies used for the markers ranged from 6 – 8 Hz. Due to intra and inter subject differences in the duration of trials, 3D segmental coordinates and putter rotations were time-normalised to 101 data points using a cubic spline algorithm. The section of the golf putt that was normalised was from the first movement during the putt backswing until the point of impact with the golf ball, the follow-through was not used for analysis. This allowed for accurate means and variation to be calculated. Following this, kinematic data were processed into segments.

Performance variability was calculated for all body segments as outlined previously within golf literature. [5] Rotations were normalised to the position at address one frame before the trial started. Following this normalisation process, the standard deviation was calculated for the 101 data points for all the trials of each participant's X, Y and Z coordinates. These were then combined via multiplication to have a single number represent the 3D rotational variability. [5,24] The equation below was used to calculate a scalene ellipsoid for each participant representing the 3D variability of the rotations for the 101 data points. [5] This was then averaged to give a mean variability volume (degrees^3):

$$VV = \frac{\sum_{n=1}^{101} \frac{4}{3}\pi\left(sd_{xi} \cdot sd_{yi} \cdot sd_{zi}\right)}{101}$$

where VV is the mean variability for each segments rotation, [sd_{xi}, sd_{yi}, sd_{zi}] are the standard deviations for all planes of movement at point *i*. When interpreting the mean variability score (VV), it was important to consider the range of rotation for each of the segments. Therefore, the mean variability score was standardised to the 3D rotations. The calculation used to calculate the average 3D distance over the trials (degrees) were:

$$\mathrm{PD} = \left(\sum_{i=1}^{101} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2}\right)$$

where PD is the performance distance of each segment, $[x_i, y_i, z_i]$ and $[x_{i+1}, y_{i+1}, z_{i+1}]$ are the positions at a point *i* during the trial and point *i*+1. This was adapted from previous literature that has calculated movement variability. [5] Performance variability was defined as the mean variability volume divided by the performance distance:

$$\mathrm{PV} = \frac{\mathrm{VV}}{\mathrm{PD}}$$

where PV is termed the performance variability. [5] This provided a volume per distance measure (degrees^3/degrees). The only segment that was analysed in a different fashion was the putter segment where only Z rotations were recorded, therefore the standard deviations were totalled and normalised by the Z rotations displacement.

Data Analysis

Segmental rotations (°) (X, Y and Z) were formulated for the pelvis, torso, left and right upper arm and left and right lower arm. These segments were selected as they have previously been analysed and are thought to contribute to the impulse being imparted on the ball during the putt. [18,25,26] Ball kinematic variables measured were: velocity (velocity (m/s) of the ball during the first 6 frames captured), side spin (cut or hook (the amount of side spin (rpm) placed on the ball during impact)), initial ball roll (whether the golf ball had positive rotation (topspin) or negative rotation (backspin) at the point of impact), forward roll (the distance at which the ball is rolling in a positive direction), vertical launch angle (the launch angle at the point of impact on the vertical axis) and the horizontal launch angle (the launch angle at the point of impact on the horizontal axis). Associations between performance variability for body segment rotation and outcome variability (ball kinematic variables) were calculated and outcome variability was tested as a coefficient of variation (%). [5]

Data were exported to the statistical software package SPSS v23 (SPSS Inc, Chicago, USA) for analysis. The data were analysed for normality using a Shapiro-Wilk test of normality and assessment of kurtosis and skewness values. The data were found to be non-parametric and therefore a Spearman's rank correlation coefficient test was carried out. The boundaries set for the coefficient statistics were; r = 0.8 – 1.0, very strong, r = 0.6 – 0.8, strong, r = 0.4 – 0.6, moderate, r = 0.2 – 0.4, weak, r = 0.0 – 0.2, no relationship. Level of significance was set at $\alpha < 0.05$.

Results

Individual performance variability for the segment rotations are presented in Figure 1. A range of variability was observed, the largest being 0.74 degrees^3/degrees for participant one. Participant eight demonstrated virtually no segment variability suggesting a very consistent movement pattern.

FIGURE ONE ABOUT HERE

Putter variation, variation of putter face angle at address and putting proficiency are presented in Table 1. Participant eight displayed the best putting proficiency (83%) this was coupled with one of the lower performance variability scores for the putter (0.17

degrees^3/degrees). A range of correlations were observed between segment variability, putter face angle at address and putting proficiency (putter and putting proficiency; no association, left forearm and putting proficiency; moderate association, right upper arm and putting proficiency; strong association). However, all correlations were identified all to be non-significant (Table 2).

TABLE 1 & 2 ABOUT HERE

Mean ball roll kinematic results are presented in Table 3 and correlation coefficients between performance measurement variability (ball roll kinematics) and segment rotation variability in Table 4. One significant correlation was identified between segment variability of the left forearm and variability of the horizontal launch angle of the golf ball (r = .92 (very strong association), p < .01). Additionally, near significant positive relationship was identified for the variability of the pelvis and horizontal launch angle (r = .65 (strong association), p = .08).

TABLE 3 & 4 ABOUT HERE

Discussion

This is one of the first studies to have considered body segment variability during the golf putting stroke. It was hypothesised that significant relationships would exist between the variability of body segments and variability of performance measures. This hypothesis can predominantly be rejected with no significant relationships identified between segment variability and putting proficiency and only one significant correlation identified between the variability of the horizontal launch angle and variability of the left forearm segment.

Within golf to date variability has only been considered for the full golf swing. [5,9,15,16] Despite this, the desired outcome for the putt is very similar to the full swing; a shot that is accurate with the correct amount of power applied. Therefore, to obtain this sought after outcome, theoretically, a movement system must be a balance of stable (persistent) and flexible motor outputs, allowing the golfer to adapt to the requirements of the shot. [11,15] It was also found no relation between performance variability and ball velocity variability, concluding that individual players use their own strategies to control performance variability so it did not affect outcome variability. [5] The results of the current study suggest this is also evident for the golf putt. With no significant correlations identified between variability of segments and putting proficiency suggest some golfers within the current study utilised or controlled performance variability to minimise output variability. Therefore, less variability isn't necessarily desirable for all golfers, with some golfers able to still putt successfully despite demonstrating more variability than others. For example participant one showed the second largest variability of the left forearm and largest variability of the pelvis (Figure 1) and had a 73% success rate. Whereas, in comparison participant seven demonstrated less segment variability and had a 67% rate, less than that of participant one and participant three who demonstrated low performance variability and was the worst performing golfer (52%). The most successful golfer (83%) participant eight demonstrated virtually no movement variability, emphasising the individual approaches observed in the current study.

It has been reported that a reduction in the variability of the hand trajectory from mid-downswing to impact improved performance for the full golf swing. [16] This however contrasting evidence exists with increased variability observed during the downswing phase. [5] Results from the current study (analysed to impact) shows that segment variability of the left forearm increased the variability of the horizontal launch angle with a very strong relationship observed (Table 4). This suggests that players that demonstrate less variability will see better performances, as in the ball starts travel in the intended direction. However, this did not translate to a positive relationship in variability of the left forearm and putting proficiency with a non-significant moderate association observed. A potential explanation for this may be the additional variability observed at address (0.48 – 1.77 degrees, Table 1). Previously, the putter face angle has been deemed to be essential regarding the initial direction of the golf putt. [13,14,18] Across the studies a range of 80-95% of the starting direction (horizontal launch angle) of a putt was accredited to putter face angle. [13,14,18] It may be the case variability of the putter face angle may accommodate some variability of the angle at address. Demonstrating that performance variability may not be detrimental to performance, whereby a different combination of rotations result in a square putter face at impact is equally as desirable as minimal variability. Another factor that could have influenced results were the range of initial ball velocity range the participants were instructed to follow. However, no participants mentioned this as an issue or factor they considered when completing the protocol.

Previously it has been observed greater movement variability of the pelvis and trunk in less proficient golfers (< 79% success rate) in comparison to more proficient golfers (> 79% success rate). [25] The current study's results are in contrast to this. Golfers in the current study demonstrated a consistent variability of the pelvis (0.01 – 0.74 degrees^3/degrees) and trunk (0.00 – 0.09 degrees^3/degrees). This includes participant one who demonstrated increased variability of the pelvis in comparison to the other participants and was not the worst performing golfer (Figure 1). Additionally, no significant correlations were observed for performance variability of the pelvis ($r = -.44$; moderate association) and trunk ($r = -.38$; weak association) with putting success rate (Table 2). Differences between the two studies may be due to the analysis techniques, whereby individual putting events during the stroke were assessed whereas the current study totalled variation for all three planes and normalised the data by the rotational displacement of each segment. It also may be due to the large intra and inter-subject variability observed in both this study and the previous article that differences actually existed between each study. [25]

It is proposed by the authors of the current study that different styles of putting may be employed by golfers. Whereby some utilise more stable motor outputs (participant eight) whereas others utilise more flexible motor outputs (participant one). More research into movement variability and putting is needed to confirm this however. This study additionally provides support for previous biomechanical literature that it is beneficial for individual based analysis within biomechanical golf analysis. [5,27] Future research needs to test a larger number of highly skilled participants to determine whether different styles of putting exist when considering movement variability. Based on the results of the current study the practical implications of the study are golf coaches should aim to ascertain whether the golfer utilises movement variability or has a consistent movement pattern and refine their current technique. It may not be beneficial to teach a new consistent putting style.

Conclusion

This is the one of the first studies to have considered movement variability effect on performance measures in the golf putt. It was established that there was no relationship between putting proficiency and performance (segment) variability. One significant relationship was observed between left forearm variability and the horizontal launch angle of the ball but this was not a detriment to performance, this may have been because of the variability of the putter face angle at initial setup. Considering the statistically non-significant results it is postulated that different styles of golf putting may exist; one whereby more stable motor outputs are utilised and secondly where more flexible motor outputs are adopted. We emphasise the need to include individual based analysis in future biomechanical golf studies. Golf coaches should aim to determine whether movement variability is being utilised where output variability is not affected resulting in equally effective performance as a golfer who demonstrates a highly consistent movement pattern.

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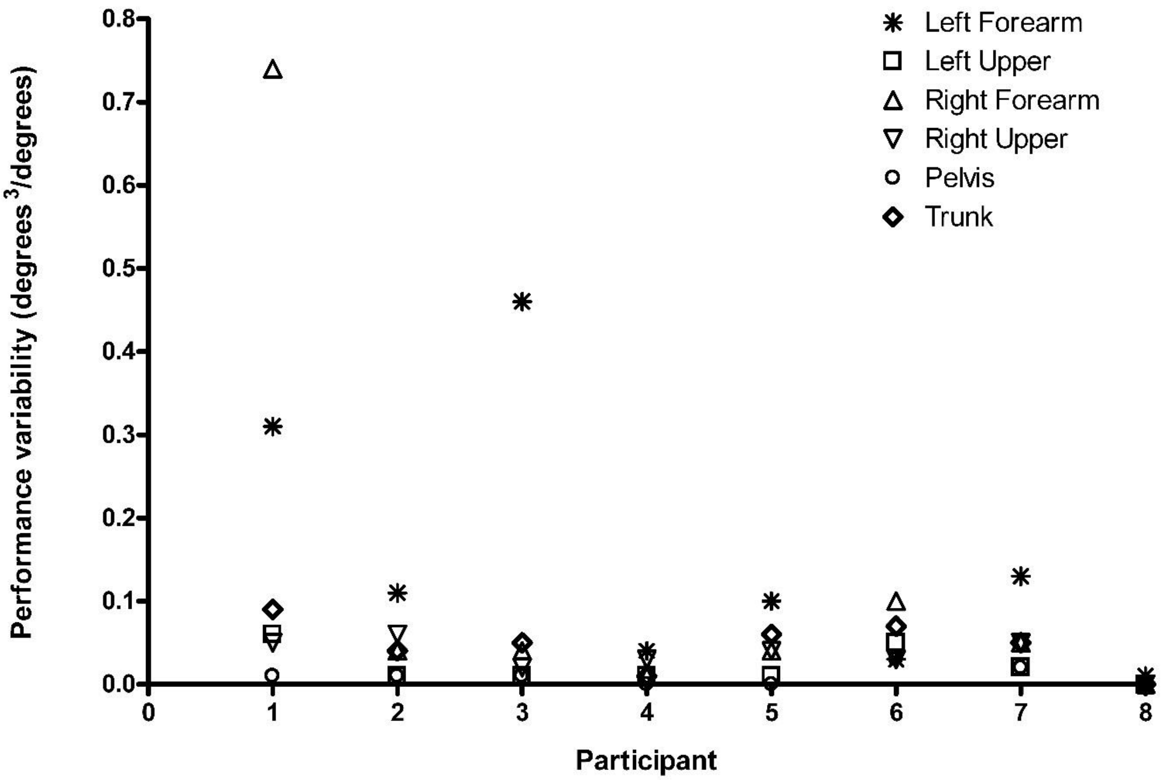

Figure 1. Scatterplot of performance variability scores for the segment rotations during the putting stroke

Table 1. Performance variability scores for the putter Z rotations during the putting stroke and the putter face angle at address.

Participant	Playing Handicap	Performance variability (degrees)	Variability of face angle at address (degrees)	Putting Proficiency (Success Rate %)
1	8	0.35	0.75	73
2	10	0.29	0.73	75
3	5	0.18	0.67	52
4	10	0.15	0.48	71
5	6	0.20	1.77	76
6	0	0.26	0.54	59
7	6	0.24	0.70	67
8	3	0.17	0.66	83

Table 2. Correlation coefficients (*r* (*p*)) between putting proficiency and segment rotation variability.

	Segment Variability							
	Left Forearm	Right Forearm	Left Upper Arm	Right Upper Arm	Pelvis	Trunk	Putter	Putter Face Angle
Putting Proficiency	-.56 (.15)	.02 (.97)	-.27 (.52)	-.61 (.11)	-.44 (.28)	-.38 (.35)	.03 (.94)	.30 (.46)

438 Table 3. Ball roll kinematic variables for all participants (mean ± SD).

Participant	Velocity (m·s^{-1})	Spin (Cut (+), Hook (-), rpm)	Initial Ball Roll (rpm)	Forward Rotation (cm)	Vertical Launch Angle (°)	Horizontal Launch Angle (°)
Average	2.22 ± 0.09	1 ± 18	18 ± 39	3.0 ± 3.3	4.0 ± 2.1	1.0 ± 1.4
1	2.28 ± 0.09	19 ± 17	65 ± 14	0.0 ± 0.1	2.0 ± 1.1	1.9 ± 1.7
2	2.11 ± 0.09	-20 ± 11	10 ± 17	1.9 ± 2.3	4.3 ± 0.6	0.2 ± 0.7
3	2.08 ± 0.11	34 ± 10	38 ± 12	0.1 ± 0.2	3.1 ± 0.6	-1.3 ± 0.9
4	2.20 ± 0.15	-5 ± 11	-17 ± 14	5.2 ± 2.5	7.1 ± 3.0	2.9 ± 1.0
5	2.33 ± 0.13	4 ± 18	75 ± 17	0.0 ± 0.1	0.8 ± 0.5	0.6 ± 1.1
6	2.22 ± 0.08	-13 ± 8	-31 ± 10	9.0 ± 1.8	5.6 ± 0.8	1.4 ± 1.2
7	2.27 ± 0.16	-6 ± 17	16 ± 11	2.2 ± 2.8	3.5 ± 0.7	0.1 ± 1.1
8	2.26 ± 0.07	-4 ± 11	-16 ± 11	5.4 ± 4.5	5.5 ± 0.9	2.3 ± 1.2

439 Key: Cut Spin refers to clockwise rotation and Hook Spin anti-clockwise rotation; a positive Vertical Launch Angle refers the
440 the trajectory of the ball in the Z axis; a negative Horizontal Launch Angle refers to the trajectory of the ball moving left of

the intended target line and a positive Horizontal Launch Angle refers to the trajectory of the ball moving right of the intended target line.

Table 4. Correlation coefficients *(r (p))* between performance measures variability and segment rotation variability.

	Left Forearm	Right Forearm	Left Upper Arm	Right Upper Arm	Pelvis	Trunk	Putter (Z rotations)
Velocity	.03 (.95)	.29 (.48)	-.31 (.45)	-.13 (.77)	-.02 (.95)	-.16 (.71)	-.38 (.35)
Side Spin	-.45 (.26)	.69 (.06)	-.17 (.70)	-.01 (.98)	.10 (.82)	.01 (.98)	.33 (.42)
Initial Ball Roll	-.45 (.27)	-.04 (.93)	-.51 (.20)	.01 (.99)	-.42 (.31)	-.65 (.08)	-.16 (.70)
Forward Roll	-.54 (.17)	.00 (1.0)	-.48 (.23)	-.05 (.91)	-.32 (.44)	-.68 (.06)	-.20 (.63)
Vertical Launch Angle	.111 (.79)	.23 (.58)	.23 (.59)	-.48 (.22)	.07 (.86)	.34 (.41)	.10 (.82)
Horizontal Launch Angle	.92 (<.01)*	-.09 (.83)	.11 (.79)	.16 (.70)	.65 (.08)	.42 (.30)	-.10 (.98)

(Significant relationship *, $p < .05$).