

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

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

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8 **KEYWORDS:** golf putting, variability, performance, kinematics, dynamical systems, golf
9 coaching

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20 **Abstract**

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

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42 **Introduction**

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

52 As outlined in dynamical systems theory, movement patterns arise, mature and develop
53 from synergistic organisation of the neuromuscular system adapting to environmental
54 factors exposed to, morphological factors and task constraints. ¹⁰ Different movement
55 patterns will develop between individuals with a unique set of different constraints,
56 allowing for different techniques to achieve the same performance outcome. ^{11,12} With the
57 golf swing being a complex and high velocity technique the existence of an invariant
58 movement pattern is unlikely. ⁵ Inter and intra-individual differences may also be apparent
59 for the golf putt, due to the smaller margins of error between a successful or missed shot.
60 ^{13,14} The consensus amongst the literature with the full golf swing in regard to movement
61 variability is to reduce variability at key swing events for successful performance. ^{9,15,16}

62 The authors however consider using a time-continuous data set for the calculation of
63 variability preferable to observing variability at specific points. ⁷ This is because the golf
64 swing or putting stroke is a continuous skill and doesn't occur only at discrete points,

65 therefore it is more applicable to observe variability across the full movement. When
66 variability across the golf swing from the start of the movement to impact was considered
67 in the full golf swing, no relationship with an outcome measure (initial velocity of the golf
68 ball) was identified. ⁵ A limitation of the aforementioned study was ball direction or
69 accuracy was not considered a performance measure. Movement variability will likely
70 affect the swing trajectories and club head angle at impact (affecting shot direction) as
71 well as the speed of movement (affecting the ball flight velocity). Club head angle at
72 impact has previously shown variability for the golf swing and golf putt. ^{13,14,17}

73 During putting it has been established that factors accounting for direction
74 consistency/variability – putter face angle (80 – 83%), the trajectory of the putter path
75 (17%) and horizontal impact point on the putter face (3%). ^{14,18} In principle if these task
76 criterion factors remain consistent with a low variability the initial launch angle of the golf
77 ball will remain consistent resulting in more putts that are successful. When considering
78 technique it should matter little as to whether a consistent technique with low variability,
79 or coordinated variability of body movement is utilised to achieve this. Therefore,
80 emphasis always being placed on a low variability movement may be incorrect when
81 considered from a dynamical systems approach and different strategies including variable
82 body movement patterns may be integral to successful putting performance. ^{5,19}

83 Movement variability for some may be a key determining factor to the reduction in
84 variance of the task criterion putter face angle at impact and therefore performance.
85 Coaching and golf putting instruction manuals traditionally has focused on encouraging
86 techniques aiming to achieve low variability, where a linear stroke is desired. ¹⁸ Scientific
87 literature has however outlined this is biomechanically complicated and difficult with

88 reliance on compensatory muscle activity keeping the putter face square whilst the body
89 rotates.¹⁴ This therefore may not be the best technique for golfers to adopt or coaches to
90 teach.

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

96 **Methods**

97 **Participants**

98 A total of 8 right-handed golfers participated in the study (age 34 ± 11 years; handicap
99 6.0 ± 3.4 (handicap range 0 – 10); height 1.80 ± 0.06 metres; mass 83.4 ± 12.2 kg). All
100 golfers were free of musculoskeletal injury for a minimum period of 3 months and played
101 a minimum of once a week. During testing participants wore their own personal golfing
102 attire and suitable dark, tight fitting non-reflective shorts and short sleeved top. All
103 participants provided written informed consent and the study was approved by the
104 institutional ethics committee of University of Hertfordshire.

105

106 **Experimental set-up**

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

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

119 Retro-reflective markers were attached to participants in accordance with a modified
120 whole body Helen Hayes marker set (total 31 markers; 14 mm) at the following anatomical
121 locations: top of head, front of head, rear head, acromion process (left and right), lateral
122 epicondyle of humerus (left and right), styloid process of the radius (left and right), on the
123 forearm intersecting the humeral epicondyle and styloid process of the radius (left and
124 right), anterior superior iliac spine (left and right), the sacrum, the thigh (intersecting the
125 plane between the hip and knee markers (left and right)), lateral aspect of the joint centre
126 of the knee (left and right), the shank (intersecting the plane between the knee and ankle
127 markers (left and right)), the lateral malleolus (left and right), the posterior aspect of the
128 calcaneus (left and right) and the third metatarsal (left and right). Markers were placed
129 directly on the skin using double sided tape, except the acromion process (pair of),
130 anterior superior iliac spine (pair of), sacrum, calcaneus (pair of) and third metatarsal (pair
131 of) which were placed on skin tight 'under-armour' clothing or shoes ensuring minimal

132 movement of markers relative to underlying body landmarks. Additionally, a marker was
133 placed on the left scapula for asymmetry and medial aspects of the knee (left and right)
134 and medial malleolus (left and right) so the joint centres of the knee and ankle could be
135 calculated.

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

144 To record the ball roll kinematics, a Quintic (Quintic Consultancy Ltd., Coventry, UK) high
145 speed camera (UI-5220RE) sampling at 220 Hz was positioned perpendicular to the
146 putting line. The Quintic v2.4 launch monitor software was used to analyse the recorded
147 ball roll. Kinematic variables analysed were initial velocity ($\text{m}\cdot\text{s}^{-1}$, calculated across the
148 first 6 recorded frames), side spin (the amount of side spin (rpm) placed on the ball during
149 impact), vertical (whether the ball was launched in the air) and horizontal (the degree to
150 which the ball deviates from the original putting line) launch angle ($^{\circ}$), initial ball roll
151 (whether the ball has positive rotation (topspin) or negative rotation (backspin) at the point
152 of impact (rpm)) and forward roll (the distance at which the ball starts positive rotation
153 (cm)). For a trial to be considered valid, the initial ball velocity had to be between 2.10 –
154 2.28 $\text{m}\cdot\text{s}^{-1}$. This was to eliminate participants' preference of either putting to hole the ball

155 successfully at very low or high velocities which could alter movement variability
156 observed. Putts that did not meet the initial ball velocity requirements were eliminated
157 from analysis. Despite this only one putt was eliminated from analysis.

158

159 **Procedure**

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

169

170 **Data Processing**

171 Three-dimensional coordinate data were processed using Cortex (Motion Analysis
172 Corporation; Santa Rosa, CA, USA) software with an Euler sequence of X, Y, Z. The 3D
173 coordinate data were filtered using a fourth-order low pass Butterworth filter, consistent
174 with previously published literature.^{16,21,22} Cut off frequency was determined using
175 residual analysis with an r^2 threshold of 0.85.²³ Cut off frequencies used for the markers
176 ranged from 6 – 8 Hz. Due to intra and inter subject differences in the duration of trials,

177 3D segmental coordinates and putter rotations were time-normalised to 101 data points
 178 using a cubic spline algorithm. The section of the golf putt that was normalised was from
 179 the first movement during the putt backswing until the point of impact with the golf ball,
 180 the follow-through was not used for analysis. This allowed for accurate means and
 181 variation to be calculated. Following this, kinematic data were processed into segments.
 182 Performance variability was calculated for all body segments as outlined previously within
 183 golf literature.⁵ Rotations were normalised to the position at address one frame before
 184 the trial started. Following this normalisation process, the standard deviation was
 185 calculated for the 101 data points for all the trials of each participant's X, Y and Z
 186 coordinates. These were then combined via multiplication to have a single number
 187 represent the 3D rotational variability.^{5,24} The equation below was used to calculate a
 188 scalene ellipsoid for each participant representing the 3D variability of the rotations for
 189 the 101 data points.⁵ This was then averaged to give a mean variability volume
 190 (degrees³):

$$191 \quad VV = \frac{\sum_{n=1}^{101} \frac{4}{3} \pi (sd_{xi} \cdot sd_{yi} \cdot sd_{zi})}{101}$$

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

$$197 \quad PD = \left(\sum_{i=1}^{101} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2} \right)$$

198 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
199 the positions at a point i during the trial and point $i+1$. This was adapted from previous
200 literature that has calculated movement variability.⁵ Performance variability was defined
201 as the mean variability volume divided by the performance distance:

$$202 \quad PV = \frac{VV}{PD}$$

203 where PV is termed the performance variability.⁵ This provided a volume per distance
204 measure (degrees³/degrees). The only segment that was analysed in a different fashion
205 was the putter segment where only Z rotations were recorded, therefore the standard
206 deviations were totalled and normalised by the Z rotations displacement.

207

208 **Data Analysis**

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

220 kinematic variables) were calculated and outcome variability was tested as a coefficient
221 of variation (%).⁵

222

223 Data were exported to the statistical software package SPSS v23 (SPSS Inc, Chicago,
224 USA) for analysis. The data were analysed for normality using a Shapiro-Wilk test of
225 normality and assessment of kurtosis and skewness values. The data were found to be
226 non-parametric and therefore a Spearman's rank correlation coefficient test was carried
227 out. The boundaries set for the coefficient statistics were; $r = 0.8 - 1.0$, very strong, $r =$
228 $0.6 - 0.8$, strong, $r = 0.4 - 0.6$, moderate, $r = 0.2 - 0.4$, weak, $r = 0.0 - 0.2$, no relationship.
229 Level of significance was set at $\alpha < 0.05$.

230 **Results**

231 Individual performance variability for the segment rotations are presented in Figure 1. A
232 range of variability was observed, the largest being 0.74 degrees³/degrees for participant
233 one. Participant eight demonstrated virtually no segment variability suggesting a very
234 consistent movement pattern.

235

236 FIGURE ONE ABOUT HERE

237

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

241 degrees³/degrees). A range of correlations were observed between segment variability,
242 putter face angle at address and putting proficiency (putter and putting proficiency; no
243 association, left forearm and putting proficiency; moderate association, right upper arm
244 and putting proficiency; strong association). However, all correlations were identified all
245 to be non-significant (Table 2).

246

247 TABLE 1 & 2 ABOUT HERE

248

249 Mean ball roll kinematic results are presented in Table 3 and correlation coefficients
250 between performance measurement variability (ball roll kinematics) and segment rotation
251 variability in Table 4. One significant correlation was identified between segment
252 variability of the left forearm and variability of the horizontal launch angle of the golf ball
253 ($r = .92$ (very strong association), $p < .01$). Additionally, near significant positive
254 relationship was identified for the variability of the pelvis and horizontal launch angle ($r =$
255 $.65$ (strong association), $p = .08$).

256

257 TABLE 3 & 4 ABOUT HERE

258

259 **Discussion**

260 This is one of the first studies to have considered body segment variability during the golf
261 putting stroke. It was hypothesised that significant relationships would exist between the

262 variability of body segments and variability of performance measures. This hypothesis
263 can predominantly be rejected with no significant relationships identified between
264 segment variability and putting proficiency and only one significant correlation identified
265 between the variability of the horizontal launch angle and variability of the left forearm
266 segment.

267 Within golf to date variability has only been considered for the full golf swing.^{5,9,15,16}
268 Despite this, the desired outcome for the putt is very similar to the full swing; a shot that
269 is accurate with the correct amount of power applied. Therefore, to obtain this sought
270 after outcome, theoretically, a movement system must be a balance of stable (persistent)
271 and flexible motor outputs, allowing the golfer to adapt to the requirements of the shot.
272^{11,15} It was also found no relation between performance variability and ball velocity
273 variability, concluding that individual players use their own strategies to control
274 performance variability so it did not affect outcome variability.⁵ The results of the current
275 study suggest this is also evident for the golf putt. With no significant correlations identified
276 between variability of segments and putting proficiency suggest some golfers within the
277 current study utilised or controlled performance variability to minimise output variability.
278 Therefore, less variability isn't necessarily desirable for all golfers, with some golfers able
279 to still putt successfully despite demonstrating more variability than others. For example
280 participant one showed the second largest variability of the left forearm and largest
281 variability of the pelvis (Figure 1) and had a 73% success rate. Whereas, in comparison
282 participant seven demonstrated less segment variability and had a 67% rate, less than
283 that of participant one and participant three who demonstrated low performance variability
284 and was the worst performing golfer (52%). The most successful golfer (83%) participant

285 eight demonstrated virtually no movement variability, emphasising the individual
286 approaches observed in the current study.

287 It has been reported that a reduction in the variability of the hand trajectory from mid-
288 downswing to impact improved performance for the full golf swing. ¹⁶ This however
289 contrasting evidence exists with increased variability observed during the downswing
290 phase. ⁵ Results from the current study (analysed to impact) shows that segment
291 variability of the left forearm increased the variability of the horizontal launch angle with a
292 very strong relationship observed (Table 4). This suggests that players that demonstrate
293 less variability will see better performances, as in the ball starts travel in the intended
294 direction. However, this did not translate to a positive relationship in variability of the left
295 forearm and putting proficiency with a non-significant moderate association observed. A
296 potential explanation for this may be the additional variability observed at address (0.48
297 – 1.77 degrees, Table 1). Previously, the putter face angle has been deemed to be
298 essential regarding the initial direction of the golf putt. ^{13,14,18} Across the studies a range
299 of 80-95% of the starting direction (horizontal launch angle) of a putt was accredited to
300 putter face angle. ^{13,14,18} It may be the case variability of the putter face angle may
301 accommodate some variability of the angle at address. Demonstrating that performance
302 variability may not be detrimental to performance, whereby a different combination of
303 rotations result in a square putter face at impact is equally as desirable as minimal
304 variability. Another factor that could have influenced results were the range of initial ball
305 velocity range the participants were instructed to follow. However, no participants
306 mentioned this as an issue or factor they considered when completing the protocol.

307 Previously it has been observed greater movement variability of the pelvis and trunk in
308 less proficient golfers (< 79% success rate) in comparison to more proficient golfers (>
309 79% success rate).²⁵ The current study's results are in contrast to this. Golfers in the
310 current study demonstrated a consistent variability of the pelvis (0.01 – 0.74
311 degrees³/degrees) and trunk (0.00 – 0.09 degrees³/degrees). This includes participant
312 one who demonstrated increased variability of the pelvis in comparison to the other
313 participants and was not the worst performing golfer (Figure 1). Additionally, no significant
314 correlations were observed for performance variability of the pelvis ($r = -.44$; moderate
315 association) and trunk ($r = -.38$; weak association) with putting success rate (Table 2).
316 Differences between the two studies may be due to the analysis techniques, whereby
317 individual putting events during the stroke were assessed whereas the current study
318 totalled variation for all three planes and normalised the data by the rotational
319 displacement of each segment. It also may be due to the large intra and inter-subject
320 variability observed in both this study and the previous article that differences actually
321 existed between each study.²⁵

322 It is proposed by the authors of the current study that different styles of putting may be
323 employed by golfers. Whereby some utilise more stable motor outputs (participant eight)
324 whereas others utilise more flexible motor outputs (participant one). More research into
325 movement variability and putting is needed to confirm this however. This study
326 additionally provides support for previous biomechanical literature that it is beneficial for
327 individual based analysis within biomechanical golf analysis.^{5,27} Future research needs
328 to test a larger number of highly skilled participants to determine whether different styles
329 of putting exist when considering movement variability. Based on the results of the current

330 study the practical implications of the study are golf coaches should aim to ascertain
331 whether the golfer utilises movement variability or has a consistent movement pattern and
332 refine their current technique. It may not be beneficial to teach a new consistent putting
333 style.

334 **Conclusion**

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

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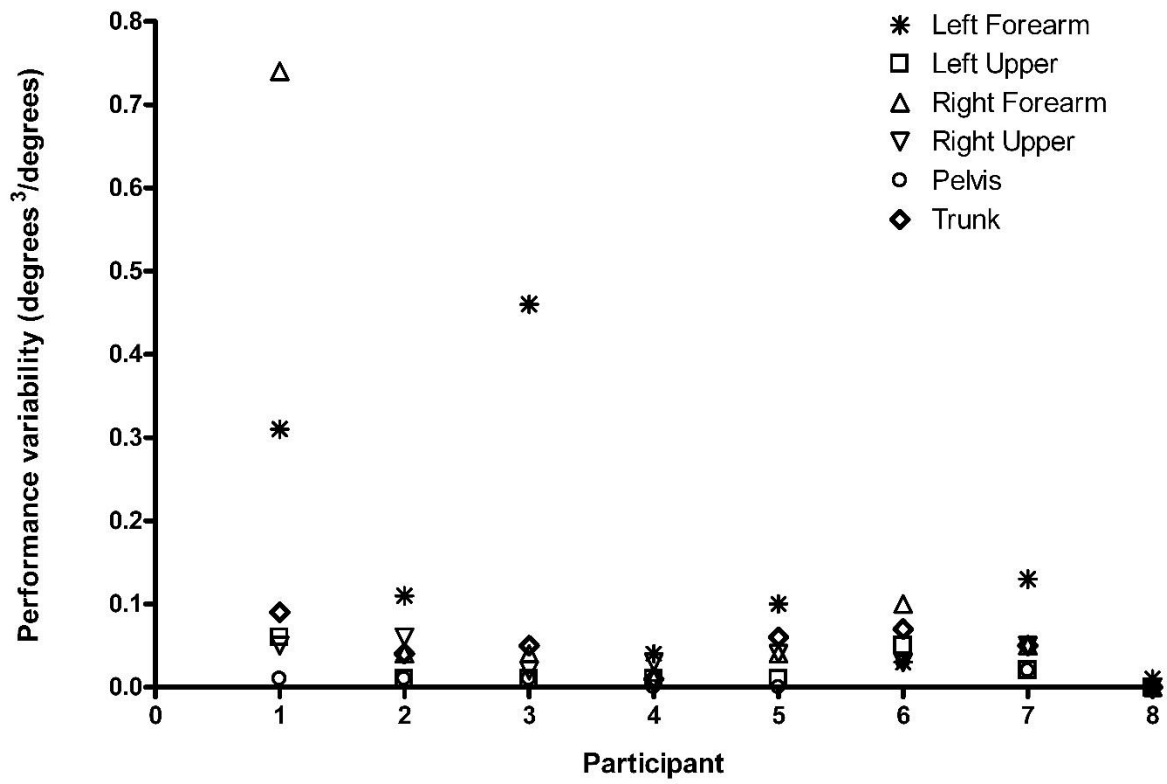
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417 Figure 1. Scatterplot of performance variability scores for the segment rotations during
 418 the putting stroke

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427 Table 1. Performance variability scores for the putter Z rotations during the putting stroke
428 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

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

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

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438 Table 3. Ball roll kinematic variables for all participants (mean \pm 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 \pm 0.09	1 \pm 18	18 \pm 39	3.0 \pm 3.3	4.0 \pm 2.1	1.0 \pm 1.4
1	2.28 \pm 0.09	19 \pm 17	65 \pm 14	0.0 \pm 0.1	2.0 \pm 1.1	1.9 \pm 1.7
2	2.11 \pm 0.09	-20 \pm 11	10 \pm 17	1.9 \pm 2.3	4.3 \pm 0.6	0.2 \pm 0.7
3	2.08 \pm 0.11	34 \pm 10	38 \pm 12	0.1 \pm 0.2	3.1 \pm 0.6	-1.3 \pm 0.9
4	2.20 \pm 0.15	-5 \pm 11	-17 \pm 14	5.2 \pm 2.5	7.1 \pm 3.0	2.9 \pm 1.0
5	2.33 \pm 0.13	4 \pm 18	75 \pm 17	0.0 \pm 0.1	0.8 \pm 0.5	0.6 \pm 1.1
6	2.22 \pm 0.08	-13 \pm 8	-31 \pm 10	9.0 \pm 1.8	5.6 \pm 0.8	1.4 \pm 1.2
7	2.27 \pm 0.16	-6 \pm 17	16 \pm 11	2.2 \pm 2.8	3.5 \pm 0.7	0.1 \pm 1.1
8	2.26 \pm 0.07	-4 \pm 11	-16 \pm 11	5.4 \pm 4.5	5.5 \pm 0.9	2.3 \pm 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

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

443 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)

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

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