

## **Reliability of an experimental method to analyse the impact point on a golf ball during putting**

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1 **Reliability of an experimental method to analyse the impact point on a golf ball**  
2 **during putting.**

3

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10 **KEYWORDS:** Biomechanics, reliability, golf putting, kinematics.

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26 **Abstract**

27 This study aimed to examine the reliability of an experimental method identifying the  
28 location of the impact point on a golf ball during putting. Forty trials were completed  
29 using a mechanical putting robot set to reproduce a putt of 3.2 m, with four different  
30 putter-ball combinations. After locating the centre of the dimple pattern (centroid) the  
31 following variables were tested; distance of the impact point from the centroid, angle  
32 of the impact point from the centroid and distance of the impact point from the  
33 centroid derived from the X, Y coordinates. Good to excellent reliability was  
34 demonstrated in all impact variables reflected in very strong relative (ICC = 0.98 –  
35 1.00) and absolute reliability (SEM% = 0.9 – 4.3%). The highest SEM% observed  
36 was 7% for the angle of the impact point from the centroid. In conclusion the  
37 experimental method was shown to be reliable at locating the centroid location of a  
38 golf ball, therefore allowing for the identification of the point of impact with the putter  
39 head. Therefore is suitable for use in subsequent studies.

40 Words: 174

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42 **Introduction**

43 Putting accounts for 43% of shots made in golf (Pelz, 2000). Despite a number of  
44 studies having identified a positive correlation between successful putting  
45 performance and overall score (Dorsel & Rotunda, 2001; Quinn, 2006; Wiseman &  
46 Chatterjee, 2006) there is still a lack of understanding of the elements that constitute  
47 a successful golf putt. Green reading (selecting correct initial ball direction), aim  
48 (placing putter face square to selected line), stroke and ball roll are the main  
49 biomechanical factors considered to contribute to a successful putt (Karlsen, Smith

50 and Nilsson, 2008). One variable that has not been analysed extensively within the  
51 literature is the impact point on the golf ball.

52

53 Literature investigating the effect of impact point on the resulting kinematics of the  
54 golf ball during putting is limited. Cross and Nathan (2007) reported the gear effect  
55 (the rotation of the moving object around its centre of mass due to an off-axis impact)  
56 in ball collisions, including the golf ball. Results demonstrated the rate of spin  
57 increased when the angle of incidence (degree of deviation away from a  
58 perpendicular collision) is increased (Cross & Nathan, 2007), which could potentially  
59 be detrimental to putting performance by increasing the variability associated with the  
60 resultant putt. Cross and Nathan (2007) concluded that the gear effect occurs as a  
61 result of static friction between the ball and object during a collision. A clear limitation  
62 of the Cross and Nathan (2007) study is that during the experimental protocol, the  
63 ball was collided off a wooden block which is not as appropriate as the use of a  
64 putter. Alessandri (1995), Lorensen and Yamrom (1992), and Penner (2002) have all  
65 proposed mathematical models of the motion of a putted golf ball over the surface of  
66 the green.

67

68 More research is required to examine whether the impact point during the putter face  
69 – ball interaction influences the success of the subsequent putt. Additionally, many  
70 ball manufacturers choose not to include any performance information regarding  
71 putting, with predominant focus on driving distance and ‘soft’ feel during pitching and  
72 chipping. Raising the question as to whether dimple design negatively affects putting.

73

74 Currently no studies have investigated how variation in the impact point on the golf  
75 ball influences the resulting kinematics of the golf ball and, furthermore, how different  
76 dimple patterns on the ball can affect the kinematic variables of the shot. No method  
77 for the analysis of the effect of the impact point has been devised or suggested within  
78 the literature. Therefore, the aim of this study was to develop and assess the  
79 reliability of a method of locating a centroid location and identifying the impact point  
80 on a golf ball. If found to be reliable, it will allow for the method to be adopted and  
81 used in further research, such as determining whether the impact point on a golf ball  
82 has an effect on the resultant kinematics of the ball during the golf putt. It was  
83 hypothesised that the method of locating a centroid location and the two methods of  
84 identifying the impact point on a golf ball would be reliable.

85

## 86 **Methods**

87

### 88 **Experimental set - up**

89 All testing was completed on an artificial putting surface (Huxley Golf., Hampshire,  
90 UK) (3.66 x 4.27 m) registering 12 on the stimpmeter (The United States Golf  
91 Association., NJ, USA). A stimpmeter is a device used to measure green speed  
92 (initial ball velocity = 1.83 m/s, ball travelled 3.65 m). A mechanical putting arm  
93 mounted on an 360 kg bearing was set up to simulate a level 3.2 m putt, with a  
94 square to square swing path to ensure a square club face at impact. This refers to a  
95 single horizontal axis perpendicular to the putting line.

96

97 Two putters with different putter face characteristics (grooved or non grooved) were  
98 selected and used for the experiment. The GEL<sup>®</sup> (GEL GOLF., Wan Chai, Hong

99 Kong) Vicis putter (grooved face) had a 69° lie (angle formed by the shaft and sole of  
100 the putter head when the putter is in a neutral position) and 2.5° loft (angle formed by  
101 the putter face and level surface when the putter is in a neutral position), and the  
102 Odyssey (Callaway Golf Europe Ltd., Surrey, UK) White Hot #3 (non-grooved) had a  
103 69° lie and 2.5° loft. Srixon (Srixon Sports Europe LTD., Hampshire, UK) Z-STAR  
104 golf balls and Titleist (Acushnet Europe Ltd., Cambridgeshire, UK) Pro V1 golf balls  
105 were used in the protocol. These particular golf balls were chosen due to them being  
106 two popular balls on the market, similar in construction and both brands premium  
107 offerings.

108

109 The golf balls were aligned using two Superline (Property Perspective Ltd, Warwick,  
110 UK) two-dimensional (2D) line lasers fixed to a 360° graduated base. One was  
111 placed directly behind the ball and the other was placed 90° to the path of the golf  
112 ball intersecting a visual putting aid printed on the ball. This split the golf ball into  
113 four equal sections ensuring the same position of the ball for each trial. A Canon  
114 (Canon Europe Ltd, Uxbridge, UK) EOS 1000d camera was situated on a stationary  
115 tripod in front of the line of the golf putt 2.5 m away from impact.

116

## 117 **Procedure**

118 The first putter was held securely in the mechanical putting arm and aligned using a  
119 swing path laminate and laser line to ensure a square to square swing path. The  
120 counterbalanced putting arm block was set to produce a putt of 3.2 m. The putting  
121 arm was attached to a weighted pole and released using an electromagnet to reduce  
122 friction to a minimum. Before the first trial was completed, a thin layer of pigmented  
123 emollient was applied to the face of the putter and smoothed out to confirm an even

124 coating. This was repeated after every trial. The golf balls were aligned using the two  
125 Superline 2D line lasers fixed to a 360° graduated base as described in the  
126 experimental set – up.

127

128 After each trial a picture was taken (Canon EOS 1000d) with the ball placed 5 cm to  
129 the right of the original position before impact, angled to show the pigmented  
130 emollient imprint on the ball and the imprint of the dimple pattern left on the putter  
131 face. The ball was then cleaned of all pigmented emollient using an alcohol wipe and  
132 the next trial was completed. Each putter-ball combination had a total of 20 trials  
133 recorded (total 80 trials).

134

## 135 **Data Processing**

### 136 **Determining the centroid location**

137 Two 2D structures (Figure 1) were developed matching the Titleist and Srixon golf  
138 ball dimple patterns using Microsoft PowerPoint 2011 to locate the centroid (0, 0  
139 coordinate of the dimple pattern). The Srixon golf ball had a single consistent size of  
140 dimple and therefore an equilateral triangle with a line drawn at every vertex fitted the  
141 dimple pattern identifying the centroid (0, 0 coordinate) of the three dimples (Figure 1  
142 A). In contrast the Titleist golf ball had two sizes of dimple (Figure 1 B), one smaller  
143 dimple encapsulated by 5 larger dimples, so a pentagon with a line drawn at every  
144 vertex fitted the dimple pattern, identifying the centroid (0, 0 coordinate) of the six  
145 dimples.

146

147 [FIGURE ONE ABOUT HERE]

148

149 **Scaling the picture**

150 The photograph from each trial was exported into Adobe Photoshop CS5 (Adobe  
151 Systems Incorporated., CA, USA) and scaled using the known length of the GEL<sup>®</sup>  
152 and Odyssey putters hosel. The hosel was selected as it was flat on each of the  
153 putters and therefore was the most appropriate part to measure accurately.

154

155 The Photoshop ruler tool was used to calculate the angle that the ball was placed at.  
156 This was to confirm that the 2D structure was placed in the correct and same  
157 position, giving the same centroid (0, 0 coordinate) for each trial.

158

159 **Calculating the centre of the impact area**

160 To calculate the centre of the impact area or the impact point, a polygon was drawn  
161 at the four outermost edges of the impact area (Figure 2). The first edge was drawn  
162 horizontally from the two outermost edges and the angle was adjusted to the angle of  
163 the dimple pattern identified (Figure 2 A) when superimposing the 2D structure on the  
164 ball. This line was then copied and superimposed at the opposite outermost edge  
165 (Figure 2 B). These steps were repeated for the two vertical lines (Figure 2 C and 2  
166 D). Each side was parallel to the opposite side and adjusted to fit correctly together.  
167 Generally this involved either lengthening or shortening the horizontal lines and this  
168 allowed for the polygon to be intersected from its four corners (Figure 2 E and 2 F)  
169 giving the centre point of the impact area.

170

171 [FIGURE TWO ABOUT HERE]

172



173 The Photoshop ruler tool was then used to measure the distance and angle of the  
174 impact point from the centroid of the dimple pattern, producing a measurable vector.  
175 Zero degrees were directly north of centroid. Additionally, the X and Y coordinates  
176 were measured from the centroid of the dimple pattern using vertical and horizontal  
177 guides. Pythagoras' theorem ( $x^2 + y^2 = z^2$ ) was used to calculate the distance of the  
178 centre of the impact area to the centroid location to provide an alternative  
179 measurement technique to compare to the accuracy of the angle distance method.

180

### 181 **Calculating the area of the impact zone**

182 Scientific image processing software ImageJ (National Institutes of Health, Bethesda,  
183 Maryland, USA) was used to calculate the surface area of the impact area. The  
184 polygon selection tool was used to draw (at 0.5 mm intervals) around the impact area  
185 imprint on the golf ball (Figure 3) and gave an output of the surface area.

186

187 [FIGURE THREE ABOUT HERE]

188

189 Each putter-ball combination was processed and then reprocessed 24 hours later  
190 under the same conditions without reference to the previous analysis to keep the  
191 reliability testing blind.

192

### 193 **Data Analysis**

194 Data were exported to statistical software packages Microsoft Excel 2011 and SPSS  
195 v19 (SPSS Inc, Chicago, USA) for analysis. Reliability was assessed for the  
196 following variables: distance of the impact point from the centroid (distance from the  
197 centroid to the centre of the impact zone), angle of the impact point from the centroid

198 (the angle of the centre of the impact zone from the centroid), X coordinate from the  
199 centroid, Y coordinate from the centroid and the resultant distance from the centroid  
200 (using the X, Y coordinates and the following formula:  $x^2 + y^2 = z^2$ ). To ensure  
201 unbiased results, the test-retest analysis was completed blind, without reference to  
202 the other days analyses.

203

204 The data were found to be normally distributed using a Shapiro – Wilk test for  
205 normality. A combination of descriptive (mean  $\pm$  SD and change in mean  $\pm$  95%  
206 confidence limits (CL) (expressed as a percentage) and reliability statistics were  
207 used. The change in mean and 95% CL stipulated an indication of absolute variation  
208 between the data sets.

209

210 Reliability statistics were the standard error of measurement expressed as a  
211 percentage (SEM%) (formula:  $SEM = SD\sqrt{1-ICC}$ ), a two – way mixed intraclass  
212 coefficient (ICC) (formula:  $\frac{1-SD^2}{SD^2}$  were used.) (Hopkins, 2000) and a Cohen's  
213 repeated measures effect size (ES). The boundaries set for the coefficient statistics  
214 were;  $r = 0.8 - 1.0$ , very strong,  $r = 0.6 - 0.8$ , strong,  $r = 0.4 - 0.6$ , moderate,  $r = 0.2$   
215  $- 0.4$ , weak,  $r = 0.0 - 0.2$ , no relationship (Salkind, 2011). In accordance with  
216 Saunders, Pyne, Telford and Hawley (2006) ES were interpreted as  $< 0.1$  as trivial,  
217  $0.1 - 0.6$  as small,  $0.6 - 1.2$  as moderate and  $> 1.2$  as large. Assessing these  
218 statistics as a collective group will provide a clear impression of the reliability and  
219 reproducibility of the method. For a reliability rating of 'excellent' the criteria  
220 threshold was change in mean  $< 5\%$ , ICC  $> 0.90$ , SEM%  $< 10\%$  and ES  $< 0.60$ . For  
221 'good' reliability, all but one criteria had to be met, for 'moderate' reliability all but two

222 criteria had to be met, and 'poor' reliability was defined as three of the criteria not  
223 being met (Joseph, Bradshaw, Kemp & Clark, 2013).

224

## 225 **Results**

### 226 **Overview of reliability**

227 Tables 1 to 4 present descriptive and reliability statistics for the impact variables.  
228 Reliability was categorised as excellent for all combined putter-ball combinations for  
229 each of the four impact variables. When putter-ball combinations are considered  
230 separately, the lowest reliability category demonstrated was good (the only failed  
231 criteria was the ES).

232

### 233 **Surface Area**

234 Surface area results (Table 1) noted excellent – good reliability categories between  
235 the four putter-ball combinations. The SEM% for all four putter-ball combinations  
236 between Test 1 and Test 2 were < 3.3% (<1 mm<sup>2</sup> when considered as a raw number)  
237 and the ICC values demonstrated very strong reliability for the combined group and  
238 individual putter golf ball combinations (ICC = 0.95 – 0.99). For the three putter-ball  
239 combinations that were categorised as demonstrating good reliability, the ES was the  
240 criteria that was broken. The largest change in mean % scores were observed for  
241 the Odyssey-Srixon combination at 3.2%. The 95% CL was consistent across groups  
242 ranging from 2.7 – 3.0%. At first glance, this variance may look relatively large,  
243 however, when considered with the change in mean percentage the largest variance  
244 between means was 6.1%. This does emphasise the fact that care is needed when  
245 processing the images for surface area.

246

247 [TABLE ONE ABOUT HERE]

248

249 **Distance of impact point from the centroid location**

250 The combined putter-ball combinations demonstrated excellent reliability for the  
251 distance of the impact point from the centroid location impact variable, this was  
252 apparent for the individual putter-ball combinations apart from the GEL<sup>®</sup>-Titleist group  
253 (Table 2). The ICC was consistently very strong (ICC = 1.00) and was coupled with  
254 consistently low SEM% values (1.6 – 2.9%). The change in mean percentage were  
255 consistently low across all four combinations along with the 95% CL. Again, the ES  
256 was the failed criteria for the GEL<sup>®</sup>-Titleist combination, catagorising the reliability as  
257 good.

258

259 [TABLE TWO ABOUT HERE]

260

261 **Distance of the impact point from the centroid derived from the X, Y**  
262 **coordinates**

263 Distance data derived from the X, Y coordinates (Table 3) demonstrated excellent  
264 reliability across the putter-ball combinations except from the GEL<sup>®</sup>- Srixon  
265 combination which was catagorised as good (SEM% = 1.6 – 3.2%; ICC = 0.99 –  
266 1.00). Descriptive statistics reassert the excellent reliability demonstrated, no  
267 irregularities were observed for any data set. The SD remained consistant for all  
268 groups across all trials, suggesting the variability observed actually existed rather  
269 than being an analysis error.

270

271 When comparing the two methods to measure the distance from the centroid location

272 the distance (measured directly) and angle method had a SEM% range of 1.6 –  
273 2.9%, when derived from the X, Y coordinates the SEM% range was 1.6 – 3.2%.  
274 Therefore, the distance from the centroid when measured directly, demonstrated  
275 marginally better absolute reliability, but when the differences in SEM% are  
276 insignificant, both methods can be considered reliable at measuring the impact point.  
277 A general trend identified that the distance derived from the X, Y coordinates were  
278 slightly shorter than that when directly measuring the impact point from the centroid,  
279 but the differences were minimal and did not increase as the distance from the  
280 centroid increased. Therefore as long as one method is chosen and all trials are  
281 analysed using the same procedure, both methods could be used to calculate the  
282 distance of the impact point from the centroid.

283

284 [TABLE THREE ABOUT HERE]

285

### 286 **Angle of the impact point from the centroid location**

287 Reliability was categorised as excellent for all putter ball combinations except from  
288 the Odyssey-Titleist combination which was categorised as good (failing the ES  
289 criteria for inclusion to excellent reliability) (Table 4). This was particularly reflected in  
290 very low SEM% (0.9 – 4.3%) and very strong ICC scores (0.98 – 1.00) showing very  
291 strong relationships between Test 1 and Test 2. Descriptive statistics confirm very  
292 strong reliability with no apparent anomalies for the combined data set or individual  
293 putter-ball combinations, with consistent SD observed.

294

295 [TABLE FOUR ABOUT HERE]

296

## 297 **Discussion and Implications**

298 The aim of this study was to test the reliability of a method to identify the impact point  
299 on a golf ball. This would allow for further analysis to see the effect on resultant ball  
300 roll kinematics. It was hypothesised that the two methods calculating the distance  
301 and direction of the impact point from the centroid would be reliable, this can be  
302 accepted. The methods were the manual measurement of the distance coupled with  
303 the angle from the centroid location and measuring the X, Y coordinates and  
304 calculating the distance of the impact point from the centroid. The results for both  
305 methods were reliable, therefore both methods are appropriate for future analysis. It  
306 was the preference of the authors to use the distance angle measurement, over the  
307 X, Y coordinates method. Additionally, this method allows for increased statistical  
308 power during multiple regression analysis, due to reducing the number of  
309 independent variables by one. Therefore this method can be considered suitable to  
310 evaluate the effect of the impact point on the subsequent kinematics of the golf ball.

311  
312 It is worthy noting that greater variability for angle from the centroid location (Table 4)  
313 (as reflected in the SEM%) was observed in the Srixon ball in comparison to the  
314 Titleist ball when hit with the GEL<sup>®</sup> putter. This could potentially reveal that certain  
315 styles of putters (grooved faced/traditional faced) demonstrate more consistency  
316 when used in conjunction with certain brands of balls with differing dimple patterns.

317  
318 It is difficult to draw comparisons to other methods that identify and analyse the  
319 impact point on a golf ball, as currently within the literature the variable has been  
320 overlooked. Research by Brouillette and Valade (2008), Brouillette (2010) and  
321 Hurrion and Hurrion (2008) has been limited to analysis of the roll of the golf ball, with

322 no discussion of the effect of the impact point. This is also apparent in studies  
323 (Alessandrini 1995; Lorensen & Yamrom, 1992 and Penner, 2002) that have used  
324 mathematical models to predict the roll of the golf ball. Karlsen et al. (2008) state  
325 that impact point accounts for 3% of direction variability, however, they only tested  
326 impact from the sweet spot in comparison to horizontal miss-hits and not the  
327 variability observed within each impact type, therefore this claim may be  
328 unsubstantiated.

329

330 A potential limitation of this study is that there is no obvious criterion measure that  
331 this method can be compared to. Therefore the validity of this method cannot be  
332 tested. Additionally, some researchers may demonstrate more subjective variability  
333 and less accuracy (in undertaking the method to locate the centroid location and  
334 subsequent impact point). To ensure reliability of future analysis using this method, it  
335 is suggested that a pilot analysis is undertaken before the main analysis. This is to  
336 certify that there is minimal variability during the data processing. By demonstrating  
337 very strong relative and absolute reliability, it shows that in this study the researcher  
338 was consistently accurate in identifying all variables.

339

## 340 **Conclusion**

341 Good to excellent reliability was demonstrated for all impact variables when the  
342 reliability statistics were interpreted as a collective group during analysis of the  
343 experimental method to determine the impact point of the putter on the golf ball. All  
344 variables had very low SEM% and demonstrated very strong relative reliability (ICC  
345 = 0.95 – 1.00). This method can be considered reliable in the assessment of the  
346 point of impact on the golf ball. Therefore, the method can be used for subsequent

347 analysis of the effect of variation in the impact point on the golf ball on subsequent  
348 ball roll kinematics. Care needs to be taken during the entire data processing  
349 method, due to the high number of stages involved in the image processing protocol.  
350 If an error is made during one stage it will ultimately effect the subsequent stages,  
351 therefore reducing relative and absolute reliability. It is suggested that all  
352 researchers test the reliability to eliminate variance in subjectivity before main  
353 analysis (assessing whether impact point affects putting direction variability) takes  
354 place.

355

## 356 **References**

357

- 358 Alessandrini, S. M. (1995). A motivational example for the numerical solution of two-  
359 point boundary-value problems. *SIAM review*, 37(3), 423-427.
- 360 Brouillette, M. (2010). Putter features that influence the rolling motion of a golf ball.  
361 *Procedia Engineering*, 2(2), 3223-3229.
- 362 Brouillette, M., & Valade, G. (2008). The effect of putter face grooves on the incipient  
363 rolling motion of a golf ball. In: Crews, D., & Lutz, R., editors. *Science and golf*  
364 *V: Proceedings of the World Scientific Congress of Golf*. Mesa, Arizona:  
365 Energy in Motion; pp. 363-368.
- 366 Cross, R., & Nathan, A. M. (2007). Experimental study of the gear effect in ball  
367 collisions. *American Journal of Physics*, 75, 658.
- 368 Dorsel, T. N., & Rotunda, R. J. (2001). Low scores, top 10 finishes, and big money:  
369 An analysis of professional golf association tour statistics and how these relate  
370 to overall performance. *Perceptual and Motor Skills*, 92(2), 575-585.



371 Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports*  
372 *Medicine, 30*(1), 1-15.

373 Hurrion, P. D., & Hurrion, R. D. (2008). An investigation into weight distribution and  
374 kinematic parameters during the putting stroke. In: Crews, D., & Lutz, R.,  
375 editors. *Science and golf V: Proceedings of the World Scientific Congress of*  
376 *Golf*. Mesa, Arizona: Energy in Motion; pp. 223-238.

377 Joseph, C. W., Bradshaw, E. J., Kemp, J., & Clark, R. A. (2013). The Interday  
378 Reliability of Ankle, Knee, Leg, and Vertical Musculoskeletal Stiffness During  
379 Hopping and Overground Running. *Journal of Applied Biomechanics, 29*(4),  
380 386-394.

381 Karlsen, J., Smith, G., & Nilsson, J. (2008). The stroke has only a minor influence on  
382 direction consistency in golf putting among elite players. *Journal of Sports*  
383 *Sciences, 26*(3), 243-250.

384 Lorensen, W. E., & Yamrom, B. (1992). Golf green visualization. *IEEE Computer*  
385 *Graphics and Applications, 12*(4), 35-44.

386 Pelz, D. T. (2000). *Dave Pelz's Putting Bible*. New York: Random House.

387 Penner, A. R. (2002). The physics of putting. *Canadian Journal of Physics, 80*(3), 83-  
388 96.

389 Quinn, R. J. (2006). Exploring correlation coefficients with golf statistics. *Teaching*  
390 *Statistics, 28*(1), 10-13.

391 Salkind, N. J. (2011). *Statistics for People who (Think They) Hate Statistics*. Portland:  
392 Sage.

393 Saunders, P. U., Telford, R. D., Pyne, D. B., Peltola, E. M., Cunningham, R. B., Gore,  
394 C. J., & Hawley, J. A. (2006). Short-term plyometric training improves running

395 economy in highly trained middle and long distance runners. *The Journal of*  
396 *Strength & Conditioning Research*, 20(4), 947-954.

397 Wiseman, F., & Chatterjee, S. (2006). Comprehensive analysis of golf performance  
398 on the PGA tour: 1990-2004. *Perceptual and Motor Skills*, 102(1), 109-117.

399 Table 1. Reliability of the impact variable surface area for the combined data set and individual putter-ball combinations.

	Test 1 (mm <sup>2</sup> ± SD)	Test 2 (mm <sup>2</sup> ± SD)	Change in Mean ± 95% CI (%)	ES	SEM%	ICC	Reliability
Odyssey-Srixon	27.40 ± 2.79	26.55 ± 3.32	3.2 ± 2.9	1.23	2.9	0.95	Good
Odyssey-Titleist	22.21 ± 3.26	21.79 ± 3.10	1.9 ± 3.0	0.76	3.0	0.97	Good
GEL <sup>®</sup> -Srixon	21.83 ± 4.05	21.86 ± 3.71	0.2 ± 2.7	0.05	2.6	0.98	Excellent
GEL <sup>®</sup> - Titleist	19.57 ± 5.19	20.19 ± 5.21	3.1 ± 2.7	0.97	2.6	0.99	Good
Average	22.75 ± 4.76	22.60 ± 4.47	0.7 ± 1.5	0.23	3.2	0.98	Excellent

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407 Table 2. Reliability of the impact variable distance from the centroid location for the combined data set and individual putter-ball  
 408 combinations.

	Test 1 (mm ± SD)	Test 2 (mm ± SD)	Change in Mean ± 95% CI (%)	ES	SEM%	ICC	Reliability
Odyssey-Srixon	1.56 ± 0.73	1.57 ± 0.73	0.6 ± 2.6	0.43	2.6	1.00	Excellent
Odyssey-Titleist	2.86 ± 0.80	2.86 ± 0.80	0.0 ± 2.1	0.00	2.1	1.00	Excellent
GEL <sup>®</sup> -Srixon	1.37 ± 0.57	1.36 ± 0.59	0.7 ± 2.9	0.55	2.9	1.00	Excellent
GEL <sup>®</sup> -Titleist	2.51 ± 0.91	2.53 ± 0.90	0.8 ± 1.6	0.70	1.6	1.00	Good
Average	2.08 ± 0.97	2.08 ± 0.97	0.0 ± 1.0	0.00	1.9	1.00	Excellent

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415

416 Table 3. Reliability of the impact variable distance derived from the X, Y coordinates from the centroid location for the combined  
 417 data set and individual putter-ball combinations.

	Test 1 (mm ± SD)	Test 2 (mm ± SD)	Change in Mean ± 95% CI (%)	ES	SEM%	ICC	Reliability
Odyssey-Srixon	1.53 ± 0.72	1.54 ± 0.73	0.7 ± 2.0	0.44	2.0	1.00	Excellent
Odyssey-Titleist	2.86 ± 0.81	2.82 ± 0.79	1.4 ± 3.2	0.50	3.2	0.99	Excellent
GEL <sup>®</sup> -Srixon	1.32 ± 0.57	1.34 ± 0.59	1.5 ± 3.0	1.09	3.0	1.00	Good
GEL <sup>®</sup> -Titleist	2.49 ± 0.89	2.50 ± 0.90	0.4 ± 1.6	0.35	1.6	1.00	Excellent
Average	2.05 ± 0.98	2.05 ± 0.97	0.0 ± 1.0	0.00	2.0	1.00	Excellent

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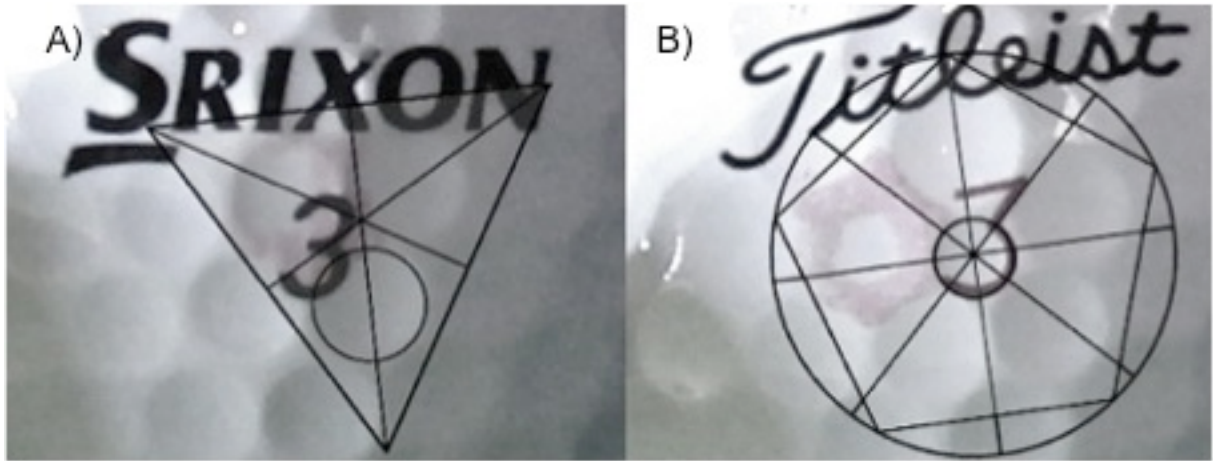
422

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424 Table 4. Reliability of the impact variable angle from the centroid location for the combined data set and individual putter-ball  
 425 combinations.

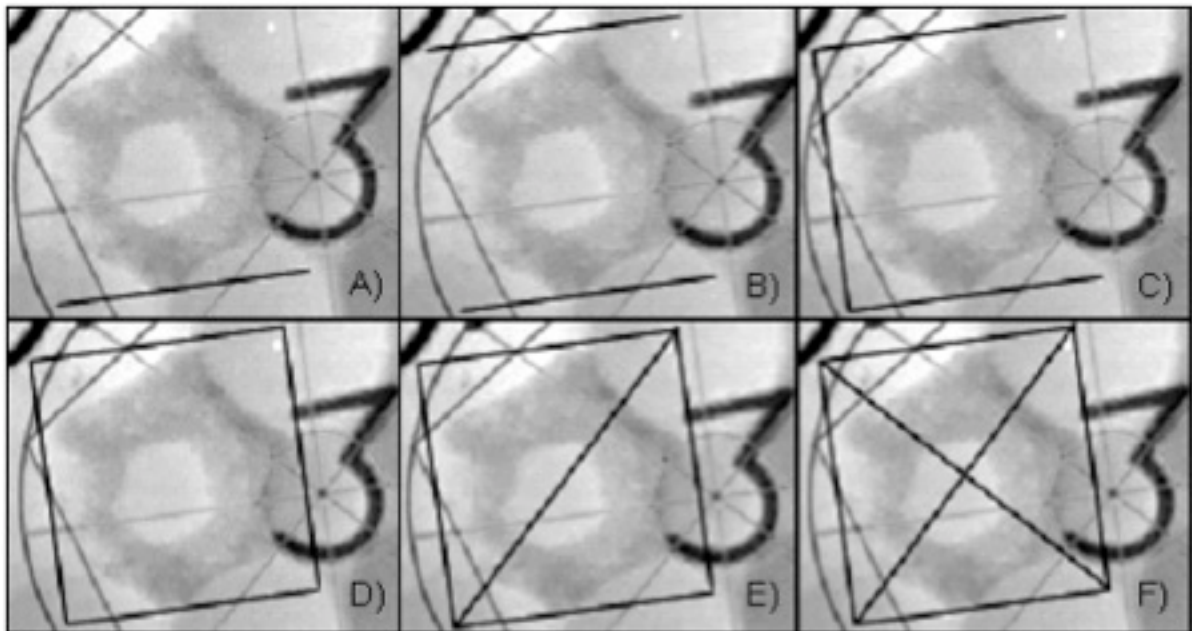
	Test 1 (° ± SD)	Test 2 (° ± SD)	Change in Mean ± 95% CI (%)	ES	SEM%	ICC	Reliability
Odyssey-Srixon	137.4 ± 33.4	137.1 ± 33.8	0.2 ± 0.9	0.09	0.9	1.00	Excellent
Odyssey-Titleist	150.6 ± 11.2	151.4 ± 11.2	0.5 ± 0.9	0.71	0.9	0.99	Good
GEL <sup>®</sup> -Srixon	108.3 ± 51.6	105.7 ± 48.6	2.4 ± 4.4	0.52	4.3	0.99	Excellent
GEL <sup>®</sup> -Titleist	134.8 ± 9.9	135.1 ± 9.8	0.1 ± 1.1	0.22	1.1	0.98	Excellent
Average	132.8 ± 34.2	132.3 ± 33.8	0.4 ± 0.9	0.15	2.0	0.99	Excellent

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428 Figure 1. Two polygon structures developed to identify the centroid of the A) Srixon  
 429 and B) Titleist golf ball.



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431 Figure 2. Step by step process of constructing and intersecting a polygon to identify  
 432 the coordinate of the impact point.



433

434 Figure 3. Titleist and Srixon golf balls with the polygon outline for calculation of the  
435 impact area.

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