

# **Acute and persistent nature of the effects of a weighted-club warm-up on golf driving performance and kinematics**

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# 1 **Acute and persistence of the effects of the SuperSpeed Golf™**

## 2 **weighted-club warm-up on golf driving performance and kinematics**

3 High-level golfers use various warm-up strategies to enhance clubhead and ball  
4 speed, including weighted equipment. We investigated the acute effects of the  
5 SuperSpeed Golf™ weighted-club warm-up on clubhead, ball, and swing  
6 kinematics, and the persistence of any acute effects in subsequent sets. Twelve  
7 competitive golfers (handicap < 3.0) completed five sets of five swings using  
8 their own drivers under two randomised warm-up conditions (Control and  
9 SuperSpeed). We compared swing, peak segment and club angular velocity, and  
10 centre of mass (COM) parameters collected using a 3D motion capture system  
11 (500 Hz) between conditions. The temporal persistence of any meaningful  
12 (Cohen's  $d \geq \textit{small}$ ) and significant ( $p \leq 0.05$ ) effect detected in the first set was  
13 investigated in subsequent sets. SuperSpeed led to *small* significant changes in  
14 clubhead speed (2.6 mph); downswing time; peak angular velocities of the torso,  
15 lead arm, and club; and two COM variables in the initial set. There was no  
16 significant change in ball speed, resulting in a *large* negative change in smash  
17 factor acutely ( $d -0.82, p = 0.009$ ). Nearly all changes observed were no longer  
18 meaningful or significant in subsequent sets. Overall, golfers can expect an  
19 increase in driving clubhead speed on the first tee using the SuperSpeed Golf™  
20 vs Control warm-up, with trivial effects from the second tee onwards.

21 Keywords: biomechanics; clubhead speed; potentiation; sport performance;  
22 strength and conditioning

## 23 **Introduction**

24 The long game in golf explains over two-thirds of the variability in scores between  
25 Professional Golfers Association (PGA) Tour competitors (Broadie, 2012). Clubhead  
26 speed is one of the main variable associated with long game carry distance (Fletcher and  
27 Hartwell, 2004; Hume, Keogh, & Reid, 2005), skill level (Keogh et al., 2009), golf  
28 handicap (Fradkin, Sherman, & Finch, 2004; Sheehan, Watsford, & Pickering  
29 Rodriguez, 2019), and professional golfers' financial earnings (PGA Tour, 2019a,  
30 2019b). Given the importance of clubhead speed on tournament outcomes; players,  
31 coaches, and researchers are continuously seeking to better understand golf swing  
32 mechanics and ways to enhance clubhead speed (Joyce, 2017; Sorbie, Gu, Baker, &  
33 Ugbolue, 2018), including the use of various warm-up strategies (Langdown, Wells,  
34 Graham, & Bridge, 2019).

35 Nearly all high-skilled golfers agree that warm-up routines enhance golfing  
36 performance and clubhead speed (Wells and Langdown, 2020), with dynamic and static  
37 stretching, air swinging with a club, and chipping, pitching, putting, and hitting full  
38 shots in common use prior to tournament play. The effect of warm-ups on swing  
39 biomechanics, clubhead speed, and ball speed, however, depends on the implemented  
40 strategy (Ehlert and Wilson, 2019). For instance, Tilley and Macfarlane (2012)  
41 demonstrated that adding functional resistance using Theraband® and rotational trunk  
42 movements to an active dynamic warm-up improved maximum driving distance, smash  
43 factor (ratio between ball and clubhead speed), and ball strike consistency in  
44 competitive golfers compared to adding linear-based resistance using a weighted bar or  
45 the active dynamic warm-up without added resistance.

46 SuperSpeed Golf™ has designed a set of weighted golf clubs (SuperSpeed  
47 Golf™ Training System, Chicago, IL) and warm-up protocol aimed at enhancing

48 clubhead and ball speed to maximise driving distance. SuperSpeed Golf™ (2020)  
49 claims to have over 600 professional golfers using their product, with high-profile  
50 players, including Phil Mickelson, seen using the weighted clubs as part of their pre-  
51 tournament warm-up routines. To date, no study has examined the effect of the  
52 SuperSpeed Golf™ warm-up protocol on golfing performance despite its anecdotally  
53 increasing use in high-level amateur and professional golfers.

54         The use of weighted equipment as part of warm-up strategies in other ball  
55 striking sports, such as baseball, is based on post-activation potentiation (PAP)  
56 mechanisms (Reyes and Dolny, 2009) and seeks to achieve post-activation performance  
57 enhancements (PAPE) (Blazevich and Babault, 2019). By definition, classical PAP is an  
58 enhanced muscle contractile response for a given level of stimulation following an  
59 intense voluntary contraction, whereas PAPE is a voluntary force or power  
60 enhancement after a high-intensity exercise-based warm-up without confirmation that  
61 PAP was evoked through twitch stimulations (Blazevich and Babault, 2019). In sports,  
62 resistance exercises that elicit a similar biomechanical movement pattern to the activity  
63 requirements are typically used to induce PAPE (Kilduff et al., 2007; Lowery et al.,  
64 2012; Scott, Ditroilo, & Marshall, 2017; Seitz, Trajano, & Haff, 2014). The use of  
65 weighted clubs is the closest equivalent of a PAPE-inducing activity replicating the  
66 sport-specific demands of golf. However, the effects of PAPE depend on numerous  
67 factors, including the transition time (Kilduff, et al., 2007; Lowery, et al., 2012), PAPE-  
68 inducing exercise (Kilduff, et al., 2007; Scott, et al., 2017; Seitz, et al., 2014), as well as  
69 resistance training experience (Scott, et al., 2017) and proportion of type II muscle  
70 fibres (Hamada, Sale, MacDougall, & Tarnopolsky, 2000) of individuals.

71         Ball striking sports have not only used heavier implements to induce PAPE as  
72 part of warm-ups, but also lighter than standard striking implements to enhance

73 performance based on overspeed principles. Overspeed training involves the use of an  
74 external stimulus to exceed unassisted maximal velocities of a specific sporting task  
75 (Leyva, Wong, & Brown, 2017). Sprinting commonly uses overspeed training via  
76 downhill (Ebben, Davies, & Clewien, 2008) or band-assisted (Upton, 2011) running, for  
77 instance, to enhance sprinting and acceleration abilities both acutely and chronically  
78 over a training period. The performance enhancements are linked to the supramaximal  
79 muscle requirements needed to perform the velocity-enhanced movements resulting  
80 from the overspeed stimulus (Ebben, et al., 2008; Upton, 2011). The SuperSpeed  
81 Golf<sup>TM</sup> warm-up protocol incorporates the use of two clubs that are lighter and one club  
82 that is heavier than standard (SuperSpeed Golf<sup>TM</sup>, 2020), suggesting that potentiation  
83 might correspondingly rely on both overspeed and PAPE mechanisms.

84 SuperSpeed Golf<sup>TM</sup> claims that performance enhancements subsequent to their  
85 weighted-club warm-up protocol can last up to 30 minutes, which contradicts PAPE  
86 research that indicate benefits from 2 minutes (Scott, et al., 2017) up to 18.5 minutes  
87 (Chiu et al., 2003). In a golf setting, 13 minutes would reflect the duration of playing  
88 one hole. From a practical perspective, two fundamental questions arise: (1) is there an  
89 acute effect of the SuperSpeed weighted-club warm-up protocol on driving performance  
90 (clubhead and ball speed) and swing kinematics; and (2) if an acute effect is present,  
91 does it persist?

92 Therefore, our first aim was to investigate the acute potentiation effect of the  
93 SuperSpeed weighted-club warm-up protocol on driving performance and kinematics;  
94 and secondly, the persistence of any effects using a simulated golf tournament scenario  
95 in a cohort of high-level amateur golfers. It was hypothesised that an increase in  
96 clubhead speed would happen following the SuperSpeed warm-up and persist for the  
97 duration of two simulated holes based on previous research (Chiu, et al., 2003). Results

98 from this study would inform athletes and coaches regarding the effectiveness and  
99 practical value of using the SuperSpeed weighted-club warm-up protocol pre-  
100 tournament.

## 101 **Methods**

### 102 *Participants*

103 Sample size requirements were calculated from standard two-tailed hypothesis  
104 equations using an 80% power ( $\beta = 0.20$ ), a 5% significance level ( $\alpha = 0.05$ ), critical  
105 values of the *t*-distribution, and test-retest reliability data on clubhead speed from  
106 previous studies (Lephart, Smoliga, Myers, Sell, & Tsai, 2007; Outram and Wheat,  
107 2019). These calculations indicated that 7 to 11 participants were required to identify  
108 reported minimal detectable mean changes (3.7 to 6.9 mph) in clubhead speeds with  
109 corresponding standard deviations (3.1 to 4.6 mph). To account for potential  
110 withdrawals or missing data, 12 participants were targeted.

111 Twelve right-hand dominant competitive golfers (7 males, 5 females; mean  $\pm$   
112 SD, age:  $22 \pm 6.9$  years; height:  $174 \pm 10$  cm; body mass:  $72.5 \pm 15.8$ ; golf handicap  $0.6$   
113  $\pm 1.8$ ) were recruited. Most participants had limited experience with the SuperSpeed  
114 clubs prior to the investigation (none,  $n = 9$ ; low, less than 10 exposures,  $n = 2$ ;  
115 moderate, 10 to 20 exposures,  $n = 1$ ; and high, more than 10 exposures,  $n = 0$ ). The  
116 inclusion criteria were: minimum of 16 years of age, free from any injuries, at least one  
117 year of resistance training experience, and registered with a New Zealand golf handicap  
118 of less than 3.0. This higher-level of performance was targeted in to reduce movement  
119 variability (Langdown, Bridge, & Li, 2012). The study was approved by the Human  
120 Research Ethics Committee of the University of Waikato [HREC (Health) #2018-35],  
121 followed international ethical standards, and adhered to the Declaration of Helsinki

122 before subject recruitment. All participants were informed about the potential risks (i.e.,  
123 delayed muscle soreness) and benefits (i.e., individual report) of study participation  
124 prior to signing the institutionally approved informed consent document.

### 125 *Study design*

126 To investigate the potentiating effect of the SuperSpeed Golf<sup>TM</sup> weighted-club warm-up  
127 protocol (**Table 1**), a within-subject repeated-measures cohort study design was used to  
128 investigate the effect of warm-up condition (Control versus SuperSpeed, **Figure 1**) on  
129 golf driving performance and biomechanics, with participants randomly assigned an  
130 order to complete the two conditions. To mitigate risk of order bias, we applied block  
131 randomisation to ensure half of the participants began with the Control condition and  
132 the other half began with the SuperSpeed condition. The two experimental sessions  
133 were performed within a 10-day period, at the same time of day, and led by a single  
134 researcher. Participants were familiarised with the testing procedures and warm-up  
135 protocols before experimentation, and performed all golf swing trials using their own  
136 golf shoes and drivers. To investigate the acute and persistence of any potentiation  
137 effect of the SuperSpeed warm-up condition, participants were required to complete  
138 five sets of five swings, walking 400 m between swing sets to simulate a golf  
139 tournament scenario.

### 140 \*\*\***FIGURE 1 / TABLE 1**\*\*\*

141 The Control warm-up condition was designed to replicate habitual warm-up  
142 routines that players would perform in preparation for tournament play (**Figure 1**).  
143 Similar to previous research on active dynamic warm-up strategies (Gergley, 2010),  
144 participants were required to swing their own clubs, progressing from shorter and  
145 heavier clubs to longer and lighter clubs before concluding their warm-up with their  
146 own drivers. The SuperSpeed warm-up (**Figure 1**) followed the manufacturer's

147 recommendations and used the SuperSpeed clubs (**Table 1**). The SuperSpeed clubs used  
148 during the warm-up are different for males and females (**Table 1**); however, the  
149 protocol remains the same with participants progressing intensity, load, and speed  
150 throughout the warm-up (**Figure 1**). The Control warm-up involved a total of 25 swings  
151 and 150 s of rest, and the SuperSpeed warm-up 27 swings and 170 s of rest, which  
152 resulted in relatively comparable work-to-rest ratios and overall intensities.

153         Following the warm-up condition, participants then completed their normal pre-  
154 shot routine, followed by swinging their own driver once. After a 90 s rest period, the  
155 data collection trials began. Each participant was instructed to complete their normal  
156 pre-shot routine prior to each recorded trial and hit the golf ball ‘as far as possible’ into  
157 the middle of the driving net using their natural golf swing. After each set of five  
158 recorded trials, participants rested for 30 s and then walked 400 m on a treadmill  
159 (Steelflex PT10 Treadmill, Steelflex Fitness, Taiwan) at a pace of 4 km·h<sup>-1</sup> (6 minutes)  
160 to replicate the length, speed, and time a typical golfer would take to walk between  
161 teeing grounds on a golf course (Smith, 2010; The R&A, 2019). Participants rested 60 s  
162 after the 400 m walk before completing another set of five swing. This process was  
163 repeated until 25 trials were completed (i.e., five sets of five swings).

#### 164 ***Kinematic data collection***

165 Testing was completed in a biomechanics laboratory using a driving mat, with  
166 participants hitting towards a net placed 5.5 metres away from the tee (**Figure 2**).  
167 Participants used their own driver and new 2018 Titleist Pro V1 golf balls covered in  
168 reflective tape to track the ball using the 3D motion capture system. Kinematic data  
169 were collected using the Qualisys Track Manager version 2.17 (build 4000), Golf  
170 Performance Visual3D Project Automated Framework version 4.0.1+66, one video  
171 camera (Oqus 210c) capturing at 50 Hz, and 10 infrared motion capture cameras (8

172 Oqus 700+, 2 Oqus 310+, Qualisys AB, Gothenburg, Sweden) capturing at 500 Hz  
173 (Joyce, Chivers, Sato, & Burnett, 2016). Prior to each session, the capture volume was  
174 calibrated using an 601.5-mm calibration wand and an L-frame that defined the  
175 Cartesian origin of the laboratory. The X-axis of the virtual laboratory was aligned with  
176 the target direction (+ towards target), Y-axis was perpendicular to the target direction  
177 (+ to the right of the target), and Z-axis was aligned with vertical (+ superior). From an  
178 initial golf-swing set-up position for all the right-hand dominant participants,  
179 movements towards the target in the X-direction represented movements towards the  
180 lead (+ left) side, and movements towards the right of the target in the Y-direction  
181 represented movements towards the tee (+ forward). In total, fifty-six 12.5 mm in  
182 diameter retro-reflective markers were affixed to participants ( $n = 50$  markers) and the  
183 club ( $n = 6$  markers) using double-sided tape (Tesa® 4965), stretch adhesive non-woven  
184 fabric (Fixomull®), and liquid adhesive (Mastisol®) following the market set  
185 guidelines from the Golf Performance Visual3D Project Automated Framework  
186 (Qualisys AB, 2017), C-Motion Wiki-Documentation (C-Motion Inc., Germantown,  
187 MD, [www.c-motion.com](http://www.c-motion.com)), and a combination of established marker sets (Bell, Brand, &  
188 Pedersen, 1989; Meister et al., 2011; Morrison, McGrath, & Wallace, 2014; Rab,  
189 Petuskey, & Bagley, 2002), as shown in **Figure 2**. Each participant stood in the middle  
190 of the calibrated volume for 1 s to allow static calibration and case-specific model  
191 definition prior to the warm-up protocols. The local coordinates of all segments were  
192 derived from this static measurement. Seven markers were removed once the static trial  
193 was completed.

194 \*\*\***FIGURE 2**\*\*\*

195 ***Data processing***

196 From the marker set, a 14-segment biomechanical model with 6 degrees of freedom at  
197 each joint was constructed in Visual3D Professional™ Software version 6.01.36 (C-  
198 Motion, Germantown, MD) to model participants. Segments included the head, upper  
199 arms, lower arms, lead hand, torso pelvis, thighs, shanks, and feet. The centre of mass  
200 (COM) of individuals was derived from these segments based on mechanical principles  
201 and Dempster's (1955) regression equations. The upper end of the torso was defined  
202 using the acromial edges and the lower end of the torso based on the iliac crest markers,  
203 and a CODA pelvis was used to define the hip joint centres (Bell, et al., 1989). In  
204 addition, three segments were constructed to define the clubface, clubhead, and ball.

205         Marker data for all golf swing experimental trials were exported to the C3D  
206 format and processed in Visual3D Professional™. The swing was broken down into six  
207 time points: takeaway (clubhead velocity exceeds 0.1 mph), half back (lead arm is  
208 horizontal), top of backswing (angular velocity of the club reaches zero), half down  
209 (lead arm is horizontal), impact (frame before initial movement of the ball covered in  
210 reflective tape), and follow-through (clubhead reaches its maximum height after impact)  
211 (Qualisys AB, 2017). Marker data were interpolated using a least-squares fit 3<sup>rd</sup> order  
212 polynomial, and filtered using a 4<sup>th</sup> order 6-Hz Butterworth bidirectional filter except  
213 for the lead arm and club markers. To account for discontinuities in the trajectories of  
214 these specific markers at impact, post-impact samples were replaced by a linear  
215 extrapolation of the clubhead path to avoid endpoint artefact (Knudson and Bahamonde,  
216 2001). Backswing data for these markers were filtered with 10 Hz, downswing with 20  
217 Hz, and follow-through with 25 Hz. In this study, only the downswing phase (from top  
218 of backswing to impact) was of interest.

219         Kinematic parameters were calculated using rigid-body analysis and Euler  
220 angles obtained from the static calibration. Body angles in the sagittal (flexion–

221 extension), coronal (adduction–abduction), and transverse (internal–external rotation)  
222 planes were calculated using an  $x$ - $y$ - $z$  Cardan sequence equivalent to the Joint  
223 Coordinate System. Pelvis and torso angles in the sagittal (anterior–posterior and  
224 flexion–extension), coronal (lead, left and trial, right side), and transverse (dominant,  
225 non–dominant rotation) planes were defined relative to the laboratory using an  $z$ - $y$ - $x$   
226 Cardan sequence based on work from Baker (2001). X-factor angles were also  
227 calculated using an  $z$ - $y$ - $x$  Cardan sequence, and defined the separation of the torso in  
228 relation to the pelvis around the Z-axis (Brown, Selbie, & Wallace, 2013). A negative  
229 angle indicated the torso rotating away from the target in relation to the pelvis during  
230 the backswing or the pelvis leading the torso (rotated towards the target) during the  
231 downswing.

### 232 ***Data extraction***

233 Swing, X-factor, angular velocity, and COM parameters were of primary interest based  
234 on 3D golf biomechanical literature (Beak et al., 2013; Joyce, 2017; Meister, et al.,  
235 2011; Sorbie, et al., 2018; Steele et al., 2018). The list of parameters extracted from the  
236 3D motion capture data are presented in **Table 2**. Since participants were directed to hit  
237 the ball into the middle of the net placed 5.5 m away, information regarding club path  
238 and ball dispersion were not analysed as it was deemed an inaccurate reflection of  
239 performance in relation to game demands.

### 240 **\*\*\*TABLE 2\*\*\***

### 241 ***Statistical analysis***

242 Means and standard deviations (mean  $\pm$  SD) were computed for all parameters to  
243 describe the data. Most parameters presented a non-normal distribution upon graphical  
244 inspection, confirmed using Shapiro-Wilk tests ( $p < 0.05$ ). Therefore, requisite log-

245 transformation of data were performed prior to statistical analysis to reduce bias arising  
246 from non-uniformity of error. Changes in mean (expressed in raw values) and Cohen's  
247 *d* standardised effect sizes (Cohen, 1988) from requisite log-transformed values were  
248 computed to compare the effect of warm-up condition on the parameters of interest. The  
249 effect was considered *small*, *moderate*, and *large* when reaching absolute threshold  
250 values of 0.2, 0.5, and 0.8; and trivial when  $< 0.20$  (Cohen, 1988). An effect was  
251 deemed *unclear* when its Cohen's *d* 95% confidence interval [lower, upper] overlapped  
252 the thresholds for small positive and negative effects (i.e.,  $d \pm 0.20$ ). Paired *t*-tests on  
253 requisite log-transformed values were used to investigate differences between warm-up  
254 conditions with the threshold for statistical significance set at  $p < 0.05$ . Only non-trivial,  
255 clear, significant effects were deemed to reflect a meaningful biomechanical change.

256 To investigate the persistence of any potentiation effect while reducing the  
257 chance of Type I errors, the effect of warm-up condition on kinematic parameters in  
258 Sets 2 to 5 was examined only for key performance indicators (i.e., clubhead and  
259 resultant ball speed) and parameters exhibiting a meaningful change in Set 1 (acute).  
260 Data were analysed using customised statistical spreadsheets (Microsoft Excel 2016,  
261 Microsoft Corp, Redmond WA, USA).

## 262 **Results**

### 263 ***Swing parameters***

264 The SuperSpeed warm-up protocol induced *small* ( $d$  0.26, 0.24, and -0.23,  $p < 0.001$ )  
265 changes in  $CHS_{peak}$ , (**Figure 3**),  $CHS_{impact}$  (**Table 3**), and downswing time (**Table 3**) in  
266 Set 1, and a *large* ( $d$  -0.82,  $p = 0.009$ ) change in smash factor (**Figure 3**). There was no  
267 significant or meaningful effect of the SuperSpeed warm-up on  $Ball_{peak\_R}$  (**Figure 3**) or  
268 all other swing parameters during Set 1 (**Supplemental Digital Content 1**).

269

\*\*\*TABLE 3\*\*\*

270 From Set 2 onward, the acute effects of the SuperSpeed warm-up on  $CHS_{peak}$  (**Figure 3**,  
271  $p < 0.003$ ) and  $CHS_{impact}$  (**Table 3**,  $p < 0.001$ ) became trivial, and non-significant with  
272 regard to the smash factor (**Figure 3**,  $p \geq 0.074$ ). The effect of the SuperSpeed warm-up  
273 on downswing time remained *small* in Set 2 and became *trivial* in Set 3 (**Table 3**).

274

\*\*\*FIGURE 3\*\*\*

275

*X-factor parameters*

276 X-factor parameters showed either non-significant or trivial differences between  
277 SuperSpeed and Control warm-up conditions in Set 1 (**Table 4**). Accordingly, the  
278 persistence of potentiation on X-factor parameters in subsequent sets was not  
279 investigated further.

280

\*\*\*TABLE 4\*\*\*

281

*Angular velocity parameters*

282 There were *small* ( $d$  0.23 to 0.32,  $p < 0.001$ ) increases in peak angular velocities of the  
283 torso, lead arm, and club subsequent the SuperSpeed compared to the Control warm-up  
284 in Set 1 (**Table 3**). The effect of SuperSpeed warm-up on the peak angular velocity of  
285 the pelvis and all timings of peak angular velocities was *trivial* or non-significant in Set  
286 1 (**Supplemental Digital Content 2**). From Set 2 onwards, only the *small* increase in  
287 the peak angular velocity of the club persisted and were maintained until Set 5, with  
288 those at the torso and lead arm becoming *trivial* (**Table 3**).

289

*Centre of mass parameters*

290 The SuperSpeed warm-up had a *small* ( $d$  0.30 and 0.23,  $p < 0.001$ ) effect on the COM  
291 position at the top of the swing and at impact in the X-direction acutely in Set 1,  
292 indicating that the COM was closer to the target. The *small* effect on COM X-position

293 at the top of the swing persisted until Set 4, but not for impact (**Table 5**). All other  
294 changes in COM parameters between warm-up conditions in Set 1 were *trivial* or not  
295 significant (**Supplemental Digital Content 3**).

296 \*\*\*TABLE 5\*\*\*

## 297 **Discussion and Implications**

298 Clubhead speed is a key parameter linked with financial earnings (PGA Tour,  
299 2019a, 2019b), golf handicap (Fradkin, et al., 2004; Sheehan, et al., 2019), driving  
300 distance (Fletcher and Hartwell, 2004; Hume, et al., 2005), and skill level (Keogh, et al.,  
301 2009), which has led to players using various warm-up strategies pre-tournament to  
302 enhance clubhead speeds, including SuperSpeed Golf™ weighted club products  
303 (SuperSpeed Golf™, 2020). In the current study, incorporating the SuperSpeed  
304 weighted clubs in a warm-up led to meaningful acute improvements in clubhead speed  
305 compared to a Control golf-specific warm-up condition (2.6 mph, **Figure 3**) in the first  
306 set of five swings performed 90 s post warm-up in agreement with our hypothesis.  
307 However, from the second set of five swings onwards, changes in clubhead speed  
308 between warm-up conditions became *trivial*, disagreeing with our hypothesis and  
309 challenging the SuperSpeed Golf™ claims of enhanced performance for up to 30  
310 minutes. From a biomechanical perspective, potentiation of clubhead speed with the  
311 SuperSpeed warm-up was associated with quicker downswing times; increased peak  
312 torso, lead arm, and club angular velocities; and COM positions closer to the target  
313 direction at the top of backswing and at impact. However, similar to clubhead speed,  
314 most of these biomechanical changes became either *trivial* or non-significant from the  
315 second set compared to a Control warm-up designed to replicate habitual warm-up  
316 routines that players would perform pre-tournament play. Additionally, there were no  
317 significant or meaningful improvements in ball speeds when contrasting SuperSpeed to

318 Control warm-up conditions (**Figure 3**), leading to a larger impaired smash factor in Set  
319 1 that tended to persist into Set 2 and Set 3. The smash factor (ratio between ball and  
320 clubhead speed) is considered an important factor to performance, reflecting the  
321 centeredness of impact, solidity of the shot, and ball strike efficiency (Lynn et al., 2013;  
322 Tilley and Macfarlane, 2012). Hence, the results indicate that golfers became less  
323 efficient subsequent the SuperSpeed warm-up, unable to increase ball speed despite an  
324 increase in clubhead speed. Overall, our findings indicate that the potentiation effect  
325 from the SuperSpeed weighted clubs and warm-up protocol on clubhead speed does not  
326 persist past the initial swing bout (i.e., first set of five swings), with no meaningful  
327 effect on ball speed.

328 In contrast to previous research on PAPE confirming a potentiation effect across  
329 several performance bouts and persistence of effects up to 18.5 minutes (Chiu, et al.,  
330 2003), the SuperSpeed warm-up condition did not produce any significant or  
331 meaningful effect from the second set of five swings onwards during a golf-simulated  
332 task compared to a Control warm-up. After the first set, the combined time of rest (90 s)  
333 and 400 m walk (6 minutes) was 7.5 minutes. The structure of our experimental  
334 protocol meant that three sets could be completed in approximately 30 minutes, the  
335 timeframe SuperSpeed Golf<sup>TM</sup> claims swing performance remains enhanced following  
336 their warm-up protocol. On-course, players would complete three tee shots within this  
337 30-minute window (The R&A, 2019). However, differences between SuperSpeed and  
338 Control warm-up conditions noted in the first set became either non-significant or trivial  
339 from the second set, which began within 14 minutes post warm-up. Research on the  
340 persistence of potentiation in high-level athletes suggests improvements in subsequent  
341 performance lasting from 4 to 12 minutes (Kilduff, et al., 2007; Lowery, et al., 2012).  
342 Participants within this study were considered high-level golfers (handicap < 3.0),

343 which can potentially explain the lack of persistence of the effect 14 minutes after the  
344 warm-up. Individualised responses were not examined herein, which could also mask  
345 persistence of effects due to the numerous factors underlying PAPE (Blazevich and  
346 Babault, 2019).

347         The intensity of the PAPE-inducing exercise can also influence the persistence  
348 of effect. Overall, research indicates that increased-intensity PAPE-inducing exercises  
349 may prolong the duration of the positive effects due to the greater increase in muscle  
350 recruitment and neural activation (Lowery, et al., 2012; Turner, Bellhouse, Kilduff, &  
351 Russell, 2015). The relatively low loads of the SuperSpeed weighted clubs could  
352 explain the lack of persistence of potentiation. However, previous research in baseball  
353 has illustrated that the use of equipment greater than 10% of standard bat mass resulted  
354 in altered biomechanics compared to that required during the sporting task (DeRenne,  
355 Ho, Hetzler, & Chai, 1992; Southard and Groomer, 2003). The use of weighted clubs  
356 heavier than the SuperSpeed ones may therefore have a detrimental effect on an  
357 athlete's biomechanical patterning and performance. Additionally, the SuperSpeed  
358 warm-up protocol sequence uses clubs of different weights in a particular order (heavy  
359 to light to mid-weight to heavy, **Table 1**). Reyes and Dolny (Reyes and Dolny, 2009)  
360 investigated using baseball bats of varying weights in a variety of sequences against a  
361 control warm-up. All weighted bat warm-ups improved bat speed, but none of the  
362 improvements were statistically significant. The order of sequencing that improved bat  
363 speed the most (standard to light to heavy) differs from the sequencing recommended  
364 by SuperSpeed Golf<sup>TM</sup> manufacturer. Future studies could investigate whether changing  
365 the order of the weighted clubs within the SuperSpeed warm-up protocol or using  
366 lighter or heavier clubs affects clubhead potentiation and movement specificity, which  
367 would confirm whether the current sequence and protocol are optimal.

368 Previous research has investigated the accumulation of fatigue during a round of  
369 golf (Doan, Newton, Kraemer, Kwon, & Scheet, 2007). Our experimental protocol  
370 examined the persistence of any potentiation effect equivalent to completing five holes  
371 based on walking distance and time (Smith, 2010; The R&A, 2019). Fatigue is minimal  
372 at such an early stage of the round (holes 1 to 6), with no significant difference in  
373 salivary endocrine markers compared to baseline seen in elite male golfers (Doan, et al.,  
374 2007). As such, we suggest that fatigue was not an overt confounder in our study  
375 findings, and would not influence performance. Previous research has incorporated re-  
376 warm-up PAPE strategies to maintain performance enhancements over an extended  
377 period (Zois, Bishop, Fairweather, Ball, & Aughey, 2013). Although an increase in 2.6  
378 mph in clubhead speed might enhance golfers performance; the R&A rules of golf  
379 prohibit the use of training aids during a round (The R&A, 2019), precluding the use of  
380 the SuperSpeed clubs as a re-warm-up strategy in tournament play. Future research  
381 could investigate the effects of using players' own clubs as a re-warm-up strategy  
382 following the SuperSpeed protocol in an attempt to re-induce potentiation during  
383 tournament play.

384 Although the acute enhancement in performance did not persist beyond the first  
385 set, it is noteworthy that there were no detrimental effects from using the weighted clubs  
386 as part of warm-up on clubhead speed or biomechanical performance measures  
387 collected, except for the smash factor. The significant negative *large* effect of the  
388 SuperSpeed warm-up on the smash factor (i.e., metric reflecting clubhead to ball speed  
389 transfer) is likely due to only 25% of participants reporting previous experience using  
390 the clubs. The changes in biomechanical patterning – albeit few and small – and acute  
391 increase in clubhead speed subsequent the SuperSpeed warm-up was most likely  
392 unfamiliar to participants. The centeredness of strike can affect ball launch conditions

393 and driving distance, accuracy, and scoring (Wallace, Otto, & Nevill, 2007). Previous  
394 exposure to the SuperSpeed warm-up protocol may enhance transference of increased  
395 clubhead to ball speeds and consolidate mastery of supramaximal movement patterns.  
396 Therefore, integration of the SuperSpeed clubs into training and competition on a  
397 regular basis to increase exposure and experience to the protocol might lead to a greater  
398 transference of the observed increase in clubhead speed to the ball, which may enhance  
399 driving distance and performance. Our study investigated the immediate effects of a  
400 single trial of the SuperSpeed warm-up, but the effects of a longer SuperSpeed protocol  
401 warrants investigation in further studies.

402         One limitation of this study was the set time of 7.5 minutes between the end of  
403 the first set and start of the second set, which does not allow for a detailed minute-to-  
404 minute time course analysis to the SuperSpeed potentiation. It is possible that day-to-  
405 day variability in golf swing kinematics and performance affected our results despite  
406 basing our sample size calculations on test-retest reliability data (Lephart, et al., 2007;  
407 Outram and Wheat, 2019), recruiting higher-level golfers to reduce movement  
408 variability (Langdown, et al., 2012), and implementing a block randomisation approach  
409 to mitigate order bias. We did not include a no warm-up condition to enhance the  
410 ecological validity of our findings given that players would complete a warm-up prior to  
411 competition. As summarised elsewhere (Evans and Tuttle, 2015), the artificial  
412 environment and surrogate performance measures used in laboratory-based research  
413 studies on golf might not accurately reflect on-course performance. The use of a net, for  
414 instance, limits the ability of golfers to focus on a driving target, and covering the golf  
415 ball in reflective tape would have altered its aerodynamic properties (Naruo and Mizota,  
416 2014). Although improving club head speed might have a resultant positive affect on

417 carry distance using the SuperSpeed warm-up, this needs further empirical evidence  
418 given that ball speed was not enhanced and driver accuracy not examined herein.

## 419 **Conclusion**

420 The SuperSpeed Golf<sup>TM</sup> weighted-club warm-up protocol led to acute  
421 improvements in clubhead speed (2.6 mph) in the first set of five swings. However,  
422 there was a lack of transference of enhanced clubhead speed to the ball likely due to  
423 lack of prior exposure of our participants to the SuperSpeed warm-up protocol and  
424 supramaximal movement patterns. The use of the SuperSpeed Golf<sup>TM</sup> weighted-club  
425 warm-up protocol compared to a golf-specific Control warm-up protocol produced no  
426 significant or meaningful difference in clubhead speed; smash factor; peak angular  
427 velocities of the torso and lead arm; or most COM measures following an initial first set  
428 of five swings. Overall, our findings imply that after use of the SuperSpeed Golf<sup>TM</sup>  
429 warm-up protocol, golfers can expect an increase in driving clubhead speed on the first  
430 tee shot, with trivial effects from the second tee onwards. It is not certain, however, that  
431 this increase observed under laboratory settings will result in improved driving distance  
432 or overall score in the field, or how accuracy might be affected. The financial, time, and  
433 practical value of investing in the SuperSpeed Golf<sup>TM</sup> product for warm-up purposes is  
434 therefore questioned especially given that use of ergogenic aids during tournament play  
435 is prohibited (The R&A, 2019).

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## 439 **Declaration of interest statement**

440 The authors report no conflict of interest.

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623 **Supplemental Digital Content 1.**

Table SDC1. Swing parameters (mean ± standard deviation) following the Control and SuperSpeed warm-up protocols in high-level amateur golfers ( $n = 12$ ). Difference between warm-ups expressed using changes in mean, Cohen’s  $d$  effect sizes and 95% confidence intervals [lower, upper], and paired  $t$ -test  $p$ -value statistics.

Parameters	Control	Super Speed <sup>a</sup>	Change in mean	Cohen’s $d$ [LL, UL] <sup>a</sup>	Magnitude <sup>a</sup>	$p$ -value <sup>a</sup>
CHS <sub>peak</sub> (mph)	<b>100.2 ± 9.7</b>	<b>102.8 ± 10.1</b>	<b>2.6 ± 3.1</b>	<b>0.26 [0.17, 0.34]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
CHS <sub>impact</sub> (mph)	<b>100.0 ± 9.7</b>	<b>102.5 ± 10.4</b>	<b>2.4 ± 3.5</b>	<b>0.24 [0.14, 0.33]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
CHS <sub>peak</sub> to CHS <sub>impact</sub> (ms)	-1.4 ± 1.5	-1.13 ± 1.74	0.30 ± 2.01	0.19 [-0.14, 0.53]	Trivial	0.253
Ball <sub>peak_R</sub> (m/s)	63.3 ± 6.4	63.6 ± 7.7	0.26 ± 3.47	0.02 [-0.15, 0.18]	Trivial	0.853
Ball <sub>peak_X</sub> (m/s)	61.8 ± 6.1	62.0 ± 7.6	0.19 ± 3.68	0.00 [-0.18, 0.18]	Trivial	0.991
Ball <sub>peak_Y</sub> (m/s)	0.2 ± 3.1	0.5 ± 3.1	0.28 ± 2.96	0.09 [-0.16, 0.34]	Trivial	0.472
Ball <sub>peak_Z</sub> (m/s)	12.9 ± 4.0	12.4 ± 6.0	-0.51 ± 5.46	-0.13 [-0.49, 0.23]	Trivial	0.480
Smash factor <sup>b</sup>	<b>1.42 ± 0.04</b>	<b>1.39 ± 0.08</b>	<b>-0.03 ± 0.08</b>	<b>-0.82 [-1.42, -0.22]</b>	<b>Large</b>	<b>0.009*</b>
Backswing time (ms)	879.6 ± 101.4	859.51 ± 83.89	-20.11 ± 54.34	-0.19 [-0.33, -0.05]	Trivial	0.010*
Downswing time (ms)	<b>284.4 ± 43.7</b>	<b>274.6 ± 42.5</b>	<b>-9.85 ± 9.04</b>	<b>-0.23 [-0.29, -0.18]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
Follow-through time (ms)	187.1 ± 25.1	184.53 ± 25.53	-2.56 ± 10.48	-0.10 [-0.22, 0.01]	Trivial	0.065
Backswing ratio	3.1 ± 0.4	3.2 ± 0.5	0.1 ± 0.2	0.10 [-0.02, 0.21]	Trivial	0.090
Follow-through ratio	0.7 ± 0.1	0.7 ± 0.1	0.00 ± 0.00	0.12 [0.03, 0.20]	Trivial	0.007*

Notes. <sup>a</sup> Analysis on log-transformed data when appropriate; <sup>b</sup> Smash factor calculated as Ball<sub>peak\_R</sub>/CHS<sub>peak</sub>. Ball<sub>peak\_R</sub>, resultant peak ball speed; Ball<sub>peak\_X</sub> target direction peak ball velocity; Ball<sub>peak\_Y</sub>, left/right peak ball velocity; Ball<sub>peak\_Z</sub>, superior-inferior peak ball velocity; CHS, clubhead speed; LL, lower limit; UL, upper limit; bolded rows cells indicate a non-trivial ( $d \geq 0.20$ ) and significant (\*paired  $t$ -test  $p < 0.05$ ) effect. Magnitude of the effect interpreted using thresholds of 0.20, 0.50, and 0.80 for *small*, *moderate*, and *large*, and *trivial*  $< 0.20$ .

625 **Supplemental Digital Content 2.**

Table SDC2. Peak and timing of peak angular velocity parameters (mean  $\pm$  standard deviation) following the Control and SuperSpeed warm-up protocols in high-level amateur golfers ( $n = 12$ ). Difference between warm-ups expressed using changes in mean, Cohen's  $d$  effect sizes and 95% confidence intervals [lower, upper], and paired  $t$ -test  $p$ -value statistics.

Parameters	Control	SuperSpeed	Change in mean	Cohen's $d$ [LL, UL] <sup>a</sup>	Magnitude <sup>a</sup>	$p$ -value <sup>a</sup>
Peak angular velocity of pelvis (°/s)	447.5 $\pm$ 76.2	460.7 $\pm$ 88.1	13.3 $\pm$ 25.4	0.14 [0.05, 0.22]	Trivial	< 0.001*
Peak angular velocity of torso (°/s)	<b>700.5 <math>\pm</math> 73.5</b>	<b>718.6 <math>\pm</math> 81.7</b>	<b>18.2 <math>\pm</math> 21.3</b>	<b>0.23 [0.16, 0.31]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
Peak angular velocity of lead arm (°/s)	<b>1053.8 <math>\pm</math> 107.9</b>	<b>1089.8 <math>\pm</math> 111.0</b>	<b>36.0 <math>\pm</math> 43.7</b>	<b>0.32 [0.21, 0.43]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
Peak angular velocity of club (°/s)	<b>2142.9 <math>\pm</math> 200.6</b>	<b>2208.9 <math>\pm</math> 205.7</b>	<b>66.0 <math>\pm</math> 79.4</b>	<b>0.32 [0.21, 0.43]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
Time before impact pelvis (ms)	121.2 $\pm$ 23.6	119.6 $\pm$ 21.6	-1.62 $\pm$ 11.26	-0.05 [-0.18, 0.07]	Trivial	0.381
Time before impact torso (ms)	85.7 $\pm$ 20.3	86.9 $\pm$ 17.7	1.17 $\pm$ 7.82	0.08 [-0.03, 0.20]	Trivial	0.148
Time before impact lead arm (ms)	82.0 $\pm$ 22.6	84.2 $\pm$ 21.1	2.23 $\pm$ 7.84	0.12 [0.02, 0.22]	Trivial	0.024*
Time before impact club (ms)	3.53 $\pm$ 2.18	3.40 $\pm$ 2.91	-0.14 $\pm$ 3.19	-0.06 [-0.51, 0.38]	Trivial	0.776

Notes. <sup>a</sup> Analysis on log-transformed data when appropriate; LL, lower limit; UL, upper limit; bolded rows cells indicate a non-trivial ( $d \geq 0.20$ ) and significant (\*paired  $t$ -test  $p < 0.05$ ) effect. Magnitude of the effect interpreted using thresholds of 0.20, 0.50, and 0.80 for *small*, *moderate*, and *large*, and *trivial*  $< 0.20$ .


627 **Supplemental Digital Content 3.**

**Table SDC3.** Centre of mass (mean  $\pm$  standard deviation) following the Control and SuperSpeed warm-up protocols in high-level amateur golfers ( $n = 12$ ). Difference between warm-ups expressed using changes in mean, Cohen's  $d$  effect sizes and 95% confidence intervals [lower, upper], and paired  $t$ -test  $p$ -value statistics.

Parameters	Control	Super Speed	Change in mean	Cohen's $d$ [LL, UL] <sup>a</sup>	Magnitude <sup>a</sup>	$p$ -value <sup>a</sup>
COM at impact X (cm)	<b>4.92 <math>\pm</math> 2.45</b>	<b>5.46 <math>\pm</math> 2.59</b>	<b>0.54 <math>\pm</math> 1.08</b>	<b>0.23 [0.04, 0.42]</b>	<b>Small</b>	<b>0.020*</b>
COM at impact Y (cm)	-0.08 $\pm$ 2.20	-0.22 $\pm$ 1.89	-0.14 $\pm$ 1.14	-0.06 [-0.21, 0.08]	Trivial	0.371
COM at impact Z (cm)	4.05 $\pm$ 1.65	4.23 $\pm$ 1.70	0.18 $\pm$ 0.67	0.11 [0.00, 0.22]	Trivial	0.059
COM at top X (cm)	<b>-5.76 <math>\pm</math> 2.41</b>	<b>-5.17 <math>\pm</math> 2.40</b>	<b>0.59 <math>\pm</math> 0.92</b>	<b>0.30 [0.16, 0.44]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
COM at top Y (cm)	1.37 $\pm$ 1.95	1.68 $\pm$ 1.74	0.31 $\pm$ 0.90	0.16 [0.03, 0.28]	Trivial	0.015*
COM at top Z (cm)	1.49 $\pm$ 1.72	01.21 $\pm$ 1.63	-0.29 $\pm$ 0.58	-0.16 [-0.26, -0.07]	Trivial	0.001*
COM at minimum vertical position X (cm)	0.30 $\pm$ 3.73	0.72 $\pm$ 3.74	0.42 $\pm$ 0.89	0.11 [0.05, 0.18]	Trivial	0.001*
COM at minimum vertical position Y (cm)	2.06 $\pm$ 2.11	2.23 $\pm$ 1.85	0.17 $\pm$ 0.96	0.08 [-0.04, 0.20]	Trivial	0.194
COM at minimum vertical position Z (cm)	-0.48 $\pm$ 1.87	-0.70 $\pm$ 1.93	-0.22 $\pm$ 0.47	-0.11 [-0.18, -0.05]	Trivial	0.001*
COM displacement velocity at impact X (cm/s)	10.05 $\pm$ 15.70	9.63 $\pm$ 13.31	-0.42 $\pm$ 5.33	-0.03 [-0.12, 0.07]	Trivial	0.570
COM displacement velocity at impact Y (cm/s)	-3.80 $\pm$ 6.94	-4.73 $\pm$ 7.08	-0.94 $\pm$ 3.49	-0.13 [-0.27, 0.01]	Trivial	0.059
COM displacement velocity at impact Z (cm/s)	26.37 $\pm$ 16.89	25.92 $\pm$ 17.28	-0.45 $\pm$ 6.90	-0.03 [-0.14, 0.09]	Trivial	0.637

*Notes.* <sup>a</sup> Analysis on log-transformed data when appropriate; COM, centre of mass; LL, lower limit; UL, upper limit; X, target direction; Y, left/right of virtual laboratory; Z, superior/inferior; bolded rows cells indicate a non-trivial ( $d \geq 0.20$ ) and significant (\*paired  $t$ -test  $p < 0.05$ ) effect. Magnitude of the effect interpreted using thresholds of 0.20, 0.50, and 0.80 for *small*, *moderate*, and *large*, and *trivial*  $< 0.20$ .

Table 1. SuperSpeed clubs, characteristics, and protocol for males and females.

	Club		Mass (g)		Protocol	
	Name	Colour	Stated <sup>a</sup>	Actual <sup>b</sup>	Male	Female
	Super light	Yellow	225.0	233.7		✓
	Light	Green	255.0	261.9	✓	✓
	Medium	Blue	290.0	297.6	✓	✓
	Heavy	Red	335.0	341.0	✓	

*Note.* All clubs are 114.3 cm in length.

<sup>a</sup>Mass stated by the manufacturer SuperSpeed Golf™ (Chicago, IL).

<sup>b</sup>Mass measure using Precisa XT6200C Instrument Ltd., Switzerland.

Table 2. Swing, x-factor, angular velocity, and centre of mass parameters extracted from the 3D motion capture data following the Control and SuperSpeed warm-up protocols in high-level amateur golfers ( $n = 12$ ).

<b>Swing parameters</b>	<b>Units</b>
Clubhead peak speed during downswing ( $CHS_{peak}$ )	mph
Clubhead impact speed ( $CHS_{impact}$ )	mph
Time between $CHS_{peak}$ and $CHS_{impact}$	ms
Resultant ball speed ( $Ball_{peak\_R}$ )	mph
Anterior-posterior ball speed ( $Ball_{peak\_X}$ )	mph
Medial-lateral ball speed ( $Ball_{peak\_Y}$ )	mph
Superior-inferior ball speed ( $Ball_{peak\_Z}$ )	mph
Smash factor (i.e., $Ball_{peak\_R}/CHS_{peak}$ )	-
Backswing time	ms
Downswing time	ms
Follow-through time	ms
Downswing ratio (backswing time: downswing time)	-
Follow-through ratio (follow-through time: downswing time)	-
<b>X-factor parameters</b>	<b>Units</b>
X-factor peak	°
X-factor at top of backswing	°
X-factor at impact	°
Difference between X-factor peak and impact	°
Difference between X-factor peak and at top of backswing (i.e., X-factor stretch)	°
Time between X-factor peak and impact	ms
Time between X-factor peak and top of backswing	ms
<b>Angular velocity parameters</b>	<b>Units</b>
Pelvis peak rotational angular velocity ( $\omega_{pelvis}$ )	°/s
Torso peak rotational angular velocity ( $\omega_{torso}$ )	°/s
Lead arm peak rotational angular velocity ( $\omega_{arm}$ )	°/s
Club peak rotational angular velocity ( $\omega_{club}$ )	°/s
Time between $\omega_{pelvis}$ and impact	ms
Time between $\omega_{torso}$ and impact	ms
Time between $\omega_{arm}$ and impact	ms
Time between $\omega_{club}$ and impact	ms
<b>Centre of mass (COM) parameters</b>	<b>Units</b>
Position at impact in relation to takeaway ( $x$ - $y$ - $z$ )	cm
Position at top of backswing in relation to takeaway ( $x$ - $y$ - $z$ )	cm
Lowest vertical position during the downswing phase in relation to takeaway ( $x$ - $y$ - $z$ )	cm
Linear displacement velocity at impact ( $x$ - $y$ - $z$ )	cm/s

Table 3. Swing parameters and peak angular velocity parameters (mean  $\pm$  standard deviation) across sets following the Control and SuperSpeed warm-up protocols in high-level amateur golfers ( $n = 12$ ). The difference between warm-ups is expressed using changes in mean, Cohen's  $d$  effect sizes and 95% confidence intervals [lower, upper], and paired  $t$ -test  $p$ -value statistics.

Set	Parameters	Control	SuperSpeed	Change in mean	Cohen's $d$ [LL, UL] <sup>a</sup>	Magnitude <sup>a</sup>	$p$ -value <sup>a</sup>
1	CHS <sub>impact</sub> (mph)	<b>100.0 <math>\pm</math> 9.7</b>	<b>102.5 <math>\pm</math> 10.4</b>	<b>2.4 <math>\pm</math> 3.5</b>	<b>0.24 [0.14, 0.33]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
2		99.7 $\pm$ 9.8	101.5 $\pm$ 9.7	1.8 $\pm$ 3.9	0.18 [0.08, 0.29]	Trivial	< 0.001*
3		99.1 $\pm$ 9.5	100.8 $\pm$ 9.0	1.7 $\pm$ 3.7	0.18 [0.08, 0.29]	Trivial	< 0.001*
4		99.6 $\pm$ 9.5	101.4 $\pm$ 9.1	1.8 $\pm$ 3.8	0.19 [0.08, 0.30]	Trivial	< 0.001*
5		100.8 $\pm$ 9.7	102.3 $\pm$ 8.6	1.5 $\pm$ 3.9	0.16 [0.05, 0.27]	Trivial	< 0.001*
1	Downswing time (ms)	<b>284.4 <math>\pm</math> 43.7</b>	<b>274.6 <math>\pm</math> 42.5</b>	<b>-9.85 <math>\pm</math> 9.04</b>	<b>-0.23 [-0.29, -0.18]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
2		<b>277.6 <math>\pm</math> 41.1</b>	<b>269.0 <math>\pm</math> 40.6</b>	<b>-8.64 <math>\pm</math> 13.28</b>	<b>-0.22 [-0.32, -0.13]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
3		277.6 $\pm$ 43.1	269.5 $\pm$ 40.8	-8.15 $\pm$ 10.68	-0.19 [-0.26, -0.12]	Trivial	< 0.001*
4		276.0 $\pm$ 38.8	268.0 $\pm$ 38.3	-8.00 $\pm$ 9.53	<b>-0.21 [-0.28, -0.14]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
5		276.9 $\pm$ 44.9	268.8 $\pm$ 43.1	-8.11 $\pm$ 8.60	-0.18 [-0.23, -0.13]	Trivial	< 0.001*
1	Peak angular velocity of torso ( $^{\circ}$ /s)	<b>700.5 <math>\pm</math> 73.5</b>	<b>718.6 <math>\pm</math> 81.7</b>	<b>18.2 <math>\pm</math> 21.3</b>	<b>0.23 [0.16, 0.31]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
2		704.6 $\pm$ 75.4	713.1 $\pm$ 83.0	8.6 $\pm$ 19.8	0.10 [0.03, 0.17]	Trivial	0.006*
3		700.3 $\pm$ 77.7	714.2 $\pm$ 77.6	13.9 $\pm$ 16.1	0.17 [0.12, 0.23]	Trivial	< 0.001*
4		699.4 $\pm$ 78.9	712.1 $\pm$ 83.6	12.7 $\pm$ 16.5	0.16 [0.10, 0.21]	Trivial	< 0.001*
5		707.7 $\pm$ 73.0	720.6 $\pm$ 78.7	12.9 $\pm$ 16.0	0.16 [0.11, 0.21]	Trivial	< 0.001*
1	Peak angular velocity of lead arm ( $^{\circ}$ /s)	<b>1053.8 <math>\pm</math> 107.9</b>	<b>1089.8 <math>\pm</math> 111.0</b>	<b>36.0 <math>\pm</math> 43.7</b>	<b>0.32 [0.21, 0.43]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
2		1051.7 $\pm$ 114.8	1074.0 $\pm$ 115.7	22.2 $\pm$ 41.8	0.19 [0.09, 0.29]	Trivial	< 0.001*
3		<b>1051.1 <math>\pm</math> 107.6</b>	<b>1075.9 <math>\pm</math> 113.5</b>	<b>24.8 <math>\pm</math> 33.7</b>	<b>0.22 [0.14, 0.30]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
4		1049.8 $\pm$ 106.0	1071.0 $\pm$ 118.6	21.2 $\pm$ 36.5	0.20 [0.11, 0.29]	Trivial	< 0.001*
5		1062.3 $\pm$ 106.3	1083.5 $\pm$ 114.5	21.2 $\pm$ 34.1	0.18 [0.10, 0.26]	Trivial	< 0.001*

1	Peak angular velocity of club (°/s)	<b>2142.9 ± 200.6</b>	<b>2208.9 ± 205.7</b>	<b>66.0 ± 79.4</b>	<b>0.32 [0.21, 0.43]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
2		<b>2147.8 ± 204.0</b>	<b>2196.4 ± 201.7</b>	<b>48.6 ± 86.9</b>	<b>0.24 [0.12, 0.35]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
3		<b>2139.0 ± 198.5</b>	<b>2182.9 ± 186.5</b>	<b>43.9 ± 102.6</b>	<b>0.22 [0.09, 0.36]</b>	<b>Small</b>	<b>0.002*</b>
4		<b>2149.2 ± 190.3</b>	<b>2194.0 ± 192.7</b>	<b>44.8 ± 86.5</b>	<b>0.23 [0.11, 0.35]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
5		<b>2173.8 ± 215.1</b>	<b>2221.8 ± 193.3</b>	<b>48.0 ± 103.2</b>	<b>0.22 [0.10, 0.35]</b>	<b>Small</b>	<b>&lt; 0.001*</b>

*Notes.* <sup>a</sup> Analysis on log-transformed data when appropriate; CHS, clubhead speed; LL, lower limit; UL, upper limit; bolded rows cells indicate a non-trivial ( $d \geq 0.20$ ) and significant (\*paired  $t$ -test  $p < 0.05$ ) effect. Magnitude of the effect interpreted using thresholds of 0.20, 0.50, and 0.80 for *small*, *moderate*, and *large*, and *trivial*  $< 0.20$ .

Table 4. X-factor parameters (mean  $\pm$  standard deviation) for the first set of 5 swings following the Control and SuperSpeed warm-up protocols in high-level amateur golfers ( $n = 12$ ). Difference between warm-ups expressed using changes in mean, Cohen's  $d$  effect sizes and 95% confidence intervals [lower, upper], and paired  $t$ -test  $p$ -value statistics.

Parameters	Control	SuperSpeed	Change in mean	Cohen's $d$ [LL, UL] <sup>a</sup>	Magnitude <sup>a</sup>	$p$ -value <sup>a</sup>
X-factor at impact (°)	-31.5 $\pm$ 7.6	-31.3 $\pm$ 8.6	0.2 $\pm$ 6.2	0.04 [-0.18, 0.25]	Trivial	0.746
X-factor peak (°)	-61.7 $\pm$ 8.8	-62.5 $\pm$ 11.0	-0.8 $\pm$ 4.1	-0.04 [-0.18, 0.09]	Trivial	0.508
X-factor at top (°)	-57.8 $\pm$ 9.0	-59.0 $\pm$ 10.9	-1.2 $\pm$ 4.1	-0.10 [-0.24, 0.04]	Trivial	0.156
X-factor peak-impact (°)	-30.3 $\pm$ 8.3	-30.3 $\pm$ 8.6	-0.01 $\pm$ 7.0	-0.01 [-0.29, 0.26]	Unclear	0.914
X-factor stretch (°)	-3.9 $\pm$ 3.9	-3.5 $\pm$ 4.1	0.4 $\pm$ 1.2	0.11 [0.03, 0.19]	Trivial	0.011*
X-factor top-impact (°)	-23.5 $\pm$ 10.0	-26.9 $\pm$ 10.6	-0.4 $\pm$ 7.6	-0.04 [-0.28, 0.20]	Trivial	0.743
X-factor time peak-impact (ms)	-21.5 $\pm$ 4.5	-21.5 $\pm$ 4.2	0.1 $\pm$ 2.3	0.02 [-0.12, 0.15]	Trivial	0.821
X-factor time max-top (ms)	7.2 $\pm$ 7.0	6.2 $\pm$ 6.3	-0.9 $\pm$ 2.3	-0.13 [-0.22, -0.04]	Trivial	0.005*

Notes. <sup>a</sup> Analysis on log-transformed data when appropriate; LL, lower limit; UL, upper limit; bolded rows cells indicate a non-trivial ( $d \geq 0.20$ ) and significant (\*paired  $t$ -test  $p < 0.05$ ) effect. Magnitude of the effect interpreted using thresholds of 0.20, 0.50, and 0.80 for *small*, *moderate*, and *large*, and *trivial*  $< 0.20$ . Effect deemed *unclear* when 95% confidence interval overlapped small positive and negative effects (i.e.,  $d \pm 0.20$ ).

Table 5. Centre of mass (COM) parameters (mean  $\pm$  standard deviation) across sets following the Control and SuperSpeed warm-up protocols in high-level amateur golfers ( $n = 12$ ). Difference between warm-ups expressed using changes in mean, Cohen's  $d$  effect sizes and 95% confidence intervals [lower, upper], and paired  $t$ -test  $p$ -value statistics.

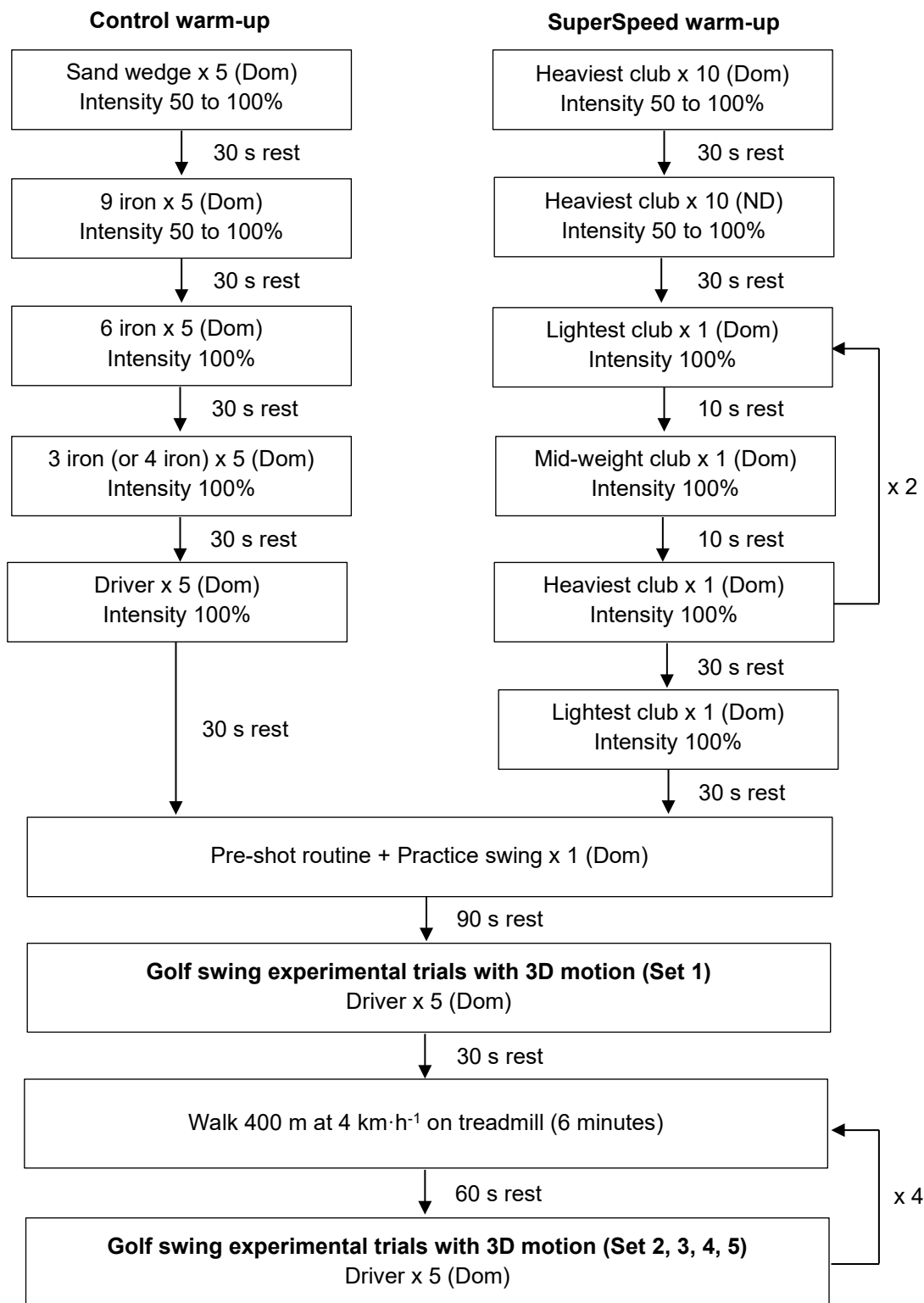
Set	Parameters	Control	SuperSpeed	Change in mean	Cohen's $d$ [LL, UL] <sup>a</sup>	Magnitude <sup>a</sup>	$p$ -value <sup>a</sup>
1	COM at top X (cm)	<b>-5.76 <math>\pm</math> 2.41</b>	<b>-5.17 <math>\pm</math> 2.40</b>	<b>0.59 <math>\pm</math> 0.92</b>	<b>0.30 [0.16, 0.44]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
2		<b>-5.55 <math>\pm</math> 2.32</b>	<b>-5.06 <math>\pm</math> 2.13</b>	<b>0.49 <math>\pm</math> 0.90</b>	<b>0.25 [0.10, 0.40]</b>	<b>Small</b>	<b>0.002*</b>
3		<b>-5.81 <math>\pm</math> 2.43</b>	<b>-5.28 <math>\pm</math> 2.62</b>	<b>0.53 <math>\pm</math> 0.84</b>	<b>0.31 [0.18, 0.46]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
4		-5.70 $\pm$ 2.50	-5.32 $\pm$ 2.56	0.38 $\pm$ 1.11	0.21 [0.06, 0.37]	Trivial	0.009*
5		-5.46 $\pm$ 2.50	-5.38 $\pm$ 2.70	0.08 $\pm$ 1.04	0.03 [-0.08, 0.15]	Trivial	0.347
1	COM at impact X (cm)	<b>4.92 <math>\pm</math> 2.45</b>	<b>5.46 <math>\pm</math> 2.59</b>	<b>0.54 <math>\pm</math> 1.08</b>	<b>0.23 [0.04, 0.42]</b>	<b>Small</b>	<b>0.020*</b>
2		4.88 $\pm$ 2.70	5.09 $\pm$ 2.52	0.22 $\pm$ 1.00	0.10 [-0.52, 0.25]	Trivial	0.192
3		<b>4.74 <math>\pm</math> 2.62</b>	<b>5.37 <math>\pm</math> 2.62</b>	<b>0.63 <math>\pm</math> 1.17</b>	<b>0.32 [0.21, 0.43]</b>	<b>Small</b>	<b>&lt; 0.001*</b>
4		4.66 $\pm$ 2.38	4.99 $\pm$ 2.57	0.33 $\pm$ 1.18	0.14 [0.00, 0.27]	Trivial	0.046*
5		5.34 $\pm$ 2.35	5.32 $\pm$ 2.73	-0.01 $\pm$ 0.98	-0.14 [-0.33, 0.05]	Trivial	0.139

Notes. <sup>a</sup> Analysis on log-transformed data when appropriate; COM, centre of mass; X, medial/lateral direction; Y, anterior/posterior direction; LL, lower limit; UL, upper limit; bolded rows cells indicate a non-trivial ( $d \geq 0.20$ ) and significant (\*paired  $t$ -test  $p < 0.05$ ) effect. Magnitude of the effect interpreted using thresholds of 0.20, 0.50, and 0.80 for *small*, *moderate*, and *large*, and *trivial*  $< 0.20$ .

631 Figure 1. Flow diagram of Control and SuperSpeed warm-up protocols for a right-hand  
632 dominant golfer. Dom, dominant: represents right-hand swings; ND, non-dominant:  
633 represents left-hand swings.  
634

635 Figure 2. Participant in static position with full marker set prior to completing a warm-  
636 up condition with graphical representation of the virtual laboratory direction. Participant  
637 markers were placed on: front, left, and right head; bilateral acromial edges, posterior  
638 and anterior upper arms, humeral lateral epicondyles, radial styloid processes, and ulnar  
639 styloid processes; leading forearm, supra wrist, and 3<sup>rd</sup> metacarpal head; bilateral supra  
640 (7<sup>th</sup> cervical region) and infra (4<sup>th</sup> thoracic region) upper back; bilateral iliac crests,  
641 anterior superior iliac spines, posterior superior iliac spine, and infra posterior superior  
642 iliac spines; bilateral posterior and anterior thighs, femoral lateral and medial  
643 epicondyles, tibial tuberosities, lateral and medial malleoli, calcanei, and 5<sup>th</sup> and 2<sup>nd</sup>  
644 metatarsal heads. For the club, four markers were spaced 5 cm apart on the shaft starting  
645 5 cm below the grip, with markers also attached to the heel and toe of the clubface. The  
646 golf ball was covered in reflective tape. Markers on the lead arm ulnar styloid process,  
647 iliac crests, anterior superior iliac spines, and clubface were removed once the static  
648 trial was completed.  
649

650 Figure 3. Mean (A) peak clubhead speed; (B) peak ball speed; and (C) smash factor  
651 across sets following the Control and SuperSpeed warm-up protocols in high-level  
652 amateur golfers ( $n = 12$ ). Smash factor calculated as peak ball speed to peak clubhead  
653 speed. Error bars represent standard deviations. Cohen's  $d$  effect size and 95%  
654 confidence intervals [lower, upper] provided above bars. A bolded effect indicates a  
655 non-trivial ( $d \geq 0.20$ ) and significant (\*paired  $t$ -test  $p < 0.05$ ) effect. Note that analysis  
656 were performed log-transformed data.



657

658 Figure 1.

659

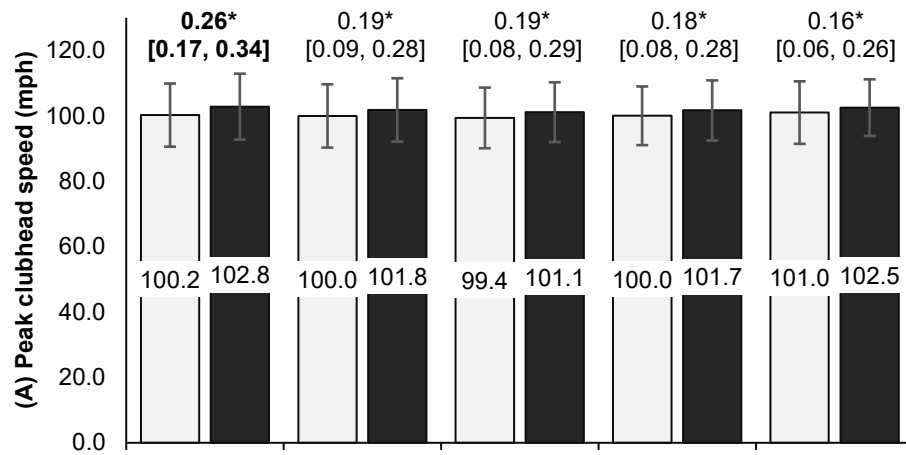


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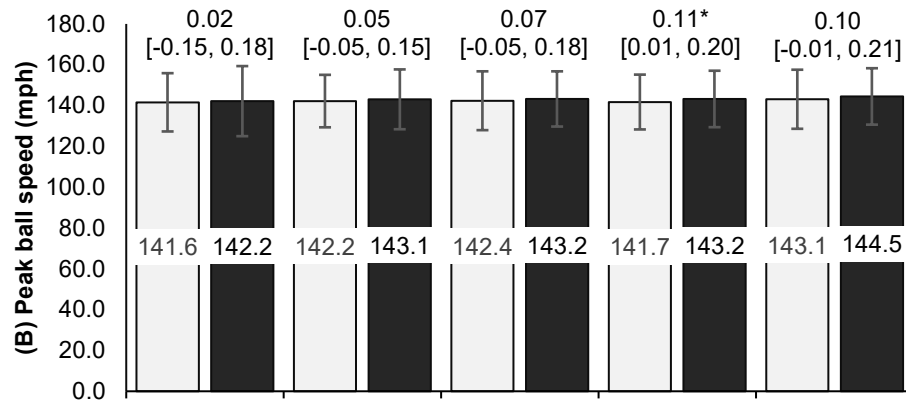
661

662 Figure 2.

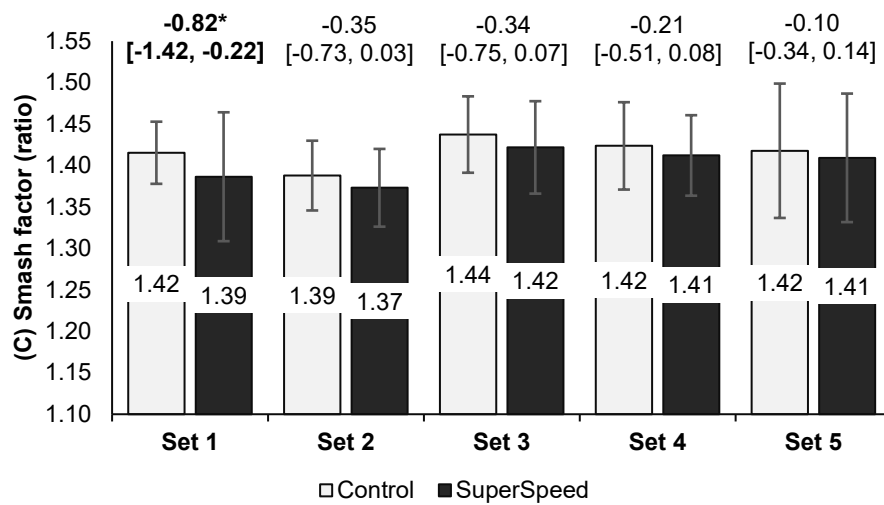
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664



665



666

667 Figure 3.