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Original Article

Title: Dimensions of Movement-Specific Reinvestment in Practice of a Golf Putting Task

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1 Introduction

2 The theory of reinvestment proposes that relatively automated skills can be disrupted by
3 attempts to consciously monitor and control the mechanics of movements (Masters, 1992;
4 Masters & Maxwell, 2008; Masters, Polman, & Hammond, 1993). The theory is underpinned
5 by an assumption that conscious monitoring and control mechanisms if used inappropriately
6 can disrupt motor automaticity (i.e., '*deautomatization*', Deikman, 1966), resulting in
7 performance that is suboptimal.

8 The likelihood that conscious monitoring and control mechanisms will become
9 involved in motor processes is a function of situational contexts, such as psychological
10 pressure, or individual personality differences. An individual's propensity for reinvestment
11 can be quantified by the Reinvestment Scale (Masters et al., 1993). Previous studies have
12 consistently demonstrated a negative association between reinvestment and performance
13 under pressure in sport (Chell, Graydon, Crowley, & Child, 2003; Jackson, Ashford, &
14 Norsworthy, 2006; Jackson, Kinrade, Hicks, & Wills, 2013; Maxwell, Masters, & Poolton,
15 2006). Although reinvestment has been extensively investigated within the context of
16 pressured situations, less is known about its role during distinctive stages of practice.
17 Moreover, reinvestment has been treated as a negative personality trait, but its negative
18 influence may be confined to certain contingencies, such as psychological pressure.

19 The pervasive view that conscious engagement in online skill execution
20 (reinvestment) necessarily hinders performance has recently been challenged by researchers
21 who have suggested that consciousness might be useful in certain circumstances (Toner &
22 Moran, 2014a, 2014b). For instance, when well-learned techniques need to be subtly changed
23 or *refined*, reinvestment might prove advantageous for performance (Carson, Collins, &
24 Richards, 2014; Toner & Moran, 2014b). For example, consciously monitoring movements

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25 might help skilled performers to identify aspects of their movements that are in need of
26 refinement and conscious control might help when refining those movements. Additionally,
27 for novices it is possible that reinvestment early in practice may facilitate the identification of
28 appropriate solutions to the motor problem (Baddeley & Wilson, 1994; Berry & Broadbent,
29 1988; Gentile, 1998).

30 Novices have a tendency to learn by ‘trial and error’. In response to unsuccessful
31 movement outcomes, individuals form and test hypotheses in a search for the most effective
32 motor solution (Masters & Poolton, 2012). Individuals with a high propensity for
33 reinvestment (as compared to a lower propensity) tend to accumulate more technical
34 knowledge as a result of practicing (Maxwell, Masters, & Eves, 2000) and also display
35 greater verbal-analytical processing of movements as indexed by neuropsychological
36 measures (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011). Given that hypothesis testing
37 can result in the accrual of technical skill-relevant knowledge that has been shown to disrupt
38 performance of relatively automated skills, researchers have advocated implicit motor
39 learning paradigms that limit the accrual of declarative knowledge (Masters & Poolton,
40 2012).

41 Prior research has also revealed that although directing conscious attention to movements
42 is debilitating during performance of well-practiced skills, it might not be debilitating during
43 performance of less-practiced skills (Beilock, Carr, MacMahon, & Starkes, 2002; Beilock &
44 Gray, 2012; Ford, Williams, & Hodges, 2005; Gray, 2004). Individuals with a high
45 propensity for reinvestment (high reinvestors) might be more inclined to engage in hypothesis
46 testing behavior, which might initially lead to inconsistencies in the pattern and
47 parameterization of movement; however, it should lead to the identification of effective
48 actions earlier in practice. For example, a novice golfer who is a high reinvestor might start
49 off making several technical adjustments in force and/or angle of the putter face at ball

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50 impact, leading to fluctuations in performance outcome, but should be quicker at determining
51 the optimal kinematics of putting stroke than a low reinvestor. Following this line of
52 reasoning, high reinvestors might have an advantage early in practice. However, later in
53 practice, when novice golfers should have figured out appropriate motor solutions (e.g.,
54 correct force to hit the ball), reinvestment should no longer support performance.

55 Jackson et al. (2006) raised concerns about whether the items of the original
56 Reinvestment Scale (RS) are a true representation of the process of reinvestment or instead a
57 mere representation of ‘...conceptually linked items that predict this process’ (p. 65). Masters
58 and colleagues have since remodeled the original RS (Movement Specific Reinvestment
59 Scale, Masters, Eves, & Maxwell, 2005), isolating two dimensions specific to movement;
60 conscious motor processing and movement self-consciousness. Conscious motor processing
61 reflects an individual’s tendency to ‘*consciously control*’ the underlying mechanics of
62 movement and movement self-consciousness reflects an individual’s tendency to harbor
63 concerns about his/her ‘*style*’ of movement such that she/he would be more concerned about
64 making a good impression when carrying out a movement. Thus, conscious motor processing
65 and movement self-consciousness seem to depict different *types* of conscious processing,
66 which may influence performance under different circumstances and potentially in different
67 ways. The limited empirical research that has examined the distinctive influence of the two
68 dimensions has primarily been conducted on clinical populations (Parkinson's disease,
69 Masters, Pall, MacMahon, & Eves, 2007; stroke, Orrell, Masters, & Eves, 2009; elderly,
70 Wong, Masters, Maxwell, & Abernethy, 2008) but this research nevertheless verifies the
71 uniqueness of the two dimensions. Despite this knowledge, researchers continue to discuss
72 reinvestment in terms of conscious motor processing and inferences about movement self-
73 consciousness have been left to speculation.

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74 Recently, Malhotra, Poolton, Wilson, Fan, and Masters (in press) examined the roles
75 of the two dimensions of movement-specific reinvestment during distinctive points in
76 learning a laparoscopic surgical task. Movement self-consciousness uniquely predicted task
77 performance early in learning and when expert-derived levels of task proficiency had been
78 attained; a stronger inclination to be movement self-conscious lengthened task completion
79 times in both instances. However, transfer to the use of a more complex cross-handed
80 technique was uniquely predicted by conscious motor processing. Malhotra et al. (in press)
81 argued that the complexity of the task (i.e., greater number of degrees of freedom) possibly
82 encouraged conscious motor processing and resulted in longer task completion times by
83 individuals with a higher propensity for conscious involvement in motor control. The strength
84 of the conclusions that can be drawn from this study is limited however, by the use of only a
85 crude performance outcome measure (completion time). Indeed, it has been frequently
86 suggested that performance outcome measures should be supplemented by assessment of the
87 underlying kinematic mechanisms by which conscious processing impacts performance
88 (Land & Tenenbaum, 2012; Pijpers, Oudejans, Holsheimer, & Bakker, 2003; Toner &
89 Moran, 2011).

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90 Technological advancements have equipped researchers with the means to capture the
91 involvement of underlying mechanisms of movement-specific reinvestment on motor
92 performance. For instance, Cooke, Kavussanu, McIntyre, Boardley, and Ring (2011),
93 recently provided some insight into the underlying kinematic processes that are linked to
94 conscious motor processing. In their study, expert golfers' performance was assessed under
95 low-, medium- and high-pressure conditions. Expert golfers tended to perform better and
96 displayed lower levels of conscious motor processing under medium as opposed to high- and
97 low-pressure conditions. More importantly, the study revealed subtle links between the
98 propensity for conscious motor processing and the kinematics of movements, with lower

99 levels of conscious motor processing in the medium-pressure condition accompanied by
100 lower impact velocities, and slower less jerky swings.

101 In a rare attempt to investigate how different *types* of conscious processing might impact
102 performance, Toner and Moran (2011) examined the differential impact of conscious *control*
103 and of conscious *monitoring* on skilled performance. Expert golfers were instructed to
104 attempt to refine their putting stroke, in order to evoke conscious motor processes, or directly
105 instructed to monitor the point of clubhead impact. The conscious control manipulation did
106 not impact putting proficiency (e.g., number of putts holed), but did result in less consistent
107 putting strokes. On the contrary, the conscious monitoring manipulation impaired putting
108 proficiency, but did not impact the consistency of putting strokes. The findings by Toner and
109 Moran (2011) demonstrate that different *types* of conscious processing may impact
110 performance and movement kinematics in different ways.

111 These findings provide some insight about how conscious motor processing might
112 manifest in performance but its role during practice is yet to be examined. Furthermore, it is
113 uncertain how movement self-consciousness might influence performance during practice.
114 Given that the two dimensions of movement-specific reinvestment have been taken to
115 represent *different types* of conscious processing they might be expected to influence
116 performance via different underpinning processes.

117 The primary aim of the current study was therefore to investigate the unique influence of
118 the two dimensions of movement-specific reinvestment on performance of a complex motor
119 skill (a golf putt) early and later in practice and to examine the underlying movement
120 kinematics that might mediate the role of the two dimensions in putting proficiency. Given
121 that the direction and magnitude of force applied to the ball by the putter face are the two
122 main factors that ultimately determine putt success, appropriate kinematic measures were

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123 selected (Pelz, 2000; Sim & Kim, 2010). Variability of impact velocity was measured to
124 assess force applied to the ball. Prior research has identified 3 main parameters that determine
125 direction of the putting stroke; with putter face angle at impact being the most important
126 determinant (80%), followed by putter path (17%) and horizontal impact point (3%) (Karlsen,
127 Smith, & Nilsson, 2008). Given that variability of the putter face angle (in degrees) at ball
128 impact (relative to the direction of aim) has been shown to be the most important parameter
129 that determines stroke direction it was used in the current study (Karlsen et al., 2008; Pelz,
130 2000). We expected that the complexity of the task would encourage individuals with a high
131 propensity for conscious motor processing to engage in hypothesis testing behavior which
132 would be reflected in a positive association between this dimension and variability of impact
133 velocity and putter face angle at impact. We were uncertain whether conscious engagement in
134 the task would immediately manifest in more proficient putting early in practice. We
135 expected any association between conscious motor processing and putting early in practice to
136 have weakened later in practice as individuals become less consciously involved in the
137 control of movement. A secondary aim of the study was to assess whether the two
138 dimensions of movement-specific reinvestment influenced change in performance as a
139 consequence of learning (i.e., performance difference from a pre-test to retention test). It was
140 unclear whether the tendency to consciously engage in motor control would be beneficial
141 (e.g., Gentile, 1998) or detrimental to learning. The relative paucity of literature on the role
142 of movement self-consciousness during practice prevented us from making empirically based
143 predictions about its influence.

145 Methods

146 Participants

147 Thirty-six sport and exercise science students from The University of Hong Kong
148 volunteered to participate in this study. One participant withdrew from the study due to
149 scheduling constraints and five others were excluded on the basis of finding the task too
150 simple.¹ Thirty participants (16 males, 14 females; Age: $M = 20.48$, $SD = 1.38$ years) were
151 eventually included in the data analysis. All participants were novice golfers with no official
152 golf handicap. Ethical approval for the study was obtained by the Institutional Review Board
153 and written informed consent was obtained from all participants.

154

155 Apparatus

156 Participants used a standard golf putter (length 89 cm) to putt golf balls to a standard size
157 hole² (10.80 cm) from a distance of 2 meters. The experiment was conducted on an artificial
158 indoor putting green and the hole was located 0.72 meters from the end of the putting green.
159 Kinematics of the putter were acquired using the three dimensional ultrasound SAM PuttLab
160 system (SAM PuttLab, Science Motion GmbH, Munich, Germany,
161 www.scienceandmotion.de). The SAM PuttLab system has an overall sampling frequency of
162 210 Hz and it records the position of the club with a precision of about one-tenth of a
163 millimeter.

164 Measures

165 Participants were required to complete the Movement Specific Reinvestment Scale (MSRS)
166 in the week prior to attending the experiment. At this point, participants were unaware of the
167 details of the study that they were participating in. The MSRS consists of five items that

¹ We excluded participants who after 10 pre-test putts scored very low on the mental demands subscale of the NASA-TLX (Hart & Staveland, 1988).

² The depth of hole was the thickness of the artificial putting green and not that of a standard size golf hole. Thus it was crucial that the ball was struck with optimum force so that it did not bounce out of the hole and/or lip out.

168 contribute to the conscious motor processing (CMP) factor, such as, “I am aware of the way
169 my body works when I am carrying out a movement” and five items that contribute to the
170 movement self-consciousness (MS-C) factor, such as, “I am concerned about my style of
171 moving”. Each item is rated on a 6-point Likert scale ranging from strongly disagree (1) to
172 strongly agree (6) such that the scores range from 5-30 points for each subscale. The MSRS
173 has acceptable test-retest reliability and good internal consistency: CMP ($r = .76$, Cronbach’s
174 $\alpha = .71$), MS-C ($r = .67$, Cronbach’s $\alpha = .78$).

175 Putting proficiency was quantified by the number of putts successfully holed (first 20
176 putts early-practice; last 20 putts later-practice). Change in putting proficiency between the
177 pre-test and the retention test was also examined. For each putt in the pre-test, early-practice,
178 later-practice and retention test, measures of variability (SD ’s) of the stroke parameters,
179 putter face angle at impact and impact velocity were extracted from the SAM Puttlab system.
180 The change in variability of these stroke parameters from the pre-test to the retention test was
181 also calculated.

182 Procedure

183 Participants attended individual practice sessions, which began with a pre-test of 10
184 putts. No instructions were provided to participants about how to putt but they were expected
185 to test hypotheses on their own (i.e., unguided discovery learning). Unguided discovery
186 learning has been shown to be associated with accrual of task specific verbalizable
187 knowledge (Hardy, Mullen, & Jones, 1996; Masters, 1992; Maxwell et al., 2000). After the
188 pre-test, participants were required to make 300 putts over the course of two days, 20 blocks
189 of 10 putts (200 putts) on Day 1 and 10 blocks of 10 putts (100 putts) on Day 2. Short rest
190 periods were provided between blocks. Fifteen minutes after completion of the final block on
191 Day 2, participants completed a retention test (10 putts). In order to keep the levels of

192 motivation high throughout training, participants were offered a financial incentive of HKD 1
193 per successful putt with an opportunity to earn a maximum of HKD 300.

194

195 Data analysis

196 Paired t-tests were conducted to examine whether putting proficiency and movement
197 variability of impact velocity and putter face angle at impact differed from the pre-test to the
198 retention test. In order to control for the inflation of a Type I error resulting from multiple
199 comparisons, Bonferroni correction was applied to the p value such that the results were
200 considered significant at the p value of .017 (.05/3). Pearson's product moment correlation
201 coefficient was used to assess the associations between the CMP and MS-C dimensions of
202 movement-specific reinvestment and putting proficiency and variability of movement
203 kinematics.

204 Mediation analyses were conducted to examine the indirect effects of multiple
205 mediators (i.e., SD impact velocity and SD putter face angle at impact) on the influence of
206 MS-C and CMP on putting proficiency. Mediation analysis was conducted using the
207 PROCESS custom dialog developed by Hayes (2013) which estimates indirect effects using a
208 non-parametric bootstrapping method. Bootstrapping is a computationally rigorous re-
209 sampling procedure that is highly recommended especially for testing mediation in small
210 sample sizes (Cerin, Taylor, Leslie, & Owen, 2006) . PROCESS uses percentile bootstrap
211 confidence intervals and bias corrected bootstrap confidence intervals³ to estimate the total,
212 direct and indirect effects of the independent variable on the dependent variable via multiple
213 mediators. Mediation can be inferred when the bootstrap confidence intervals of the indirect
214 effect do not include zero, suggesting that the effect is significantly different from zero.

³ In the current study we used bias corrected bootstrapping as it is considered more powerful and robust to Type I errors (Preacher & Hayes, 2008).

215 Results

216 Paired t-tests revealed that participants had significantly higher putting proficiency in the
217 retention test ($M = 6.27, SD = 2.53$) compared to the pre-test ($M = 3.23, SD = 1.92$), $t(29) =$
218 $6.65, p < .001, 95\% CI = 2.10$ to 3.97 . Participants also had lower variability of impact
219 velocity in the retention test ($M = 90.56, SD = 43.42$) compared to the pre-test ($M = 274.80,$
220 $SD = 175.92$), $t(28) = 5.53, p < .001, 95\% CI = 115.95$ to 252.53 , and lower variability of
221 putter face angle at impact ($M = 1.49, SD = 0.63$) compared to the pre-test ($M = 2.50, SD =$
222 1.17), $t(28) = 4.10, p < .001, 95\% CI = 0.50$ to 1.51 .

223 Descriptive Statistics

224 Table 1 provides the descriptive data and Pearson's product moment correlations of all
225 variables. Early in practice, MS-C scores ($p = .036$) were negatively correlated with *SD*
226 impact velocity as were CMP scores ($p = .019$). CMP was also negatively correlated with *SD*
227 putter face angle at impact ($p = .047$). Lower variability of impact velocity ($p < .001$) and
228 putter face angle at impact ($p = .002$) was associated with higher putting proficiency. Early in
229 practice, MS-C was positively correlated with putting proficiency ($p = .005$) and there was a
230 trend for a similar association with CMP ($p = .065$). Later in practice, MS-C scores were
231 negatively correlated with *SD* impact velocity ($p = .022$) and CMP scores were negatively
232 correlated with *SD* putter face angle at impact ($p = .004$). Lower variability of impact velocity
233 was associated with higher putting proficiency ($p < .001$) but variability of putter face angle
234 at impact was not significantly correlated with putting proficiency ($p = .223$). MS-C was
235 positively correlated with putting proficiency ($p = .003$) but CMP was not ($p = .442$). MS-C
236 ($p = .024$) was significantly correlated with change in *SD* impact velocity and CMP
237 approached significance ($p = .069$); higher scores on MS-C and CMP were associated with
238 less change in *SD* impact velocity from pre-test to retention test. MS-C and CMP were not

239 significantly correlated with change in putting proficiency and change in *SD* putter face angle
240 at impact (p 's > .05).

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242 Mediation

243 Mediation analyses were carried out to examine whether variability of the stroke parameters
244 of impact velocity and putter face angle at impact mediated the role of MS-C and CMP in
245 putting proficiency early and later in practice. Although CMP was not significantly correlated
246 with putting proficiency early and later in practice, mediation was still conducted with this
247 variable as a significant association between the independent and dependent variable is not
248 necessary for mediation to occur (Cerin & MacKinnon, 2009; MacKinnon, Krull, &
249 Lockwood, 2000; Shrout & Bolger, 2002). Separate mediation models were run for MS-C
250 and CMP in which they were entered as the independent variables, and putting proficiency
251 was entered as a dependent variable with *SD* impact velocity and *SD* putter face angle at
252 impact entered as multiple mediators. Multiple mediation models were chosen over a series
253 of simple mediation models to exclude the possibility of parameter bias due to omitted
254 variables (Preacher & Hayes, 2008).

255 ***Figure 1 a and Figure 1b near here***

256 Figure 1a displays the unstandardized regression coefficients of the mediation model
257 for predicting the impact of MS-C on putting proficiency early in practice via variability of
258 the stroke parameters. As can be seen in Figure 1a, MS-C was significantly associated with
259 *SD* impact velocity ($p = .036$) such that higher scores on MS-C were associated with less
260 variable impact velocity, but MS-C was not significantly associated with *SD* putter face angle
261 at impact ($p = .154$). *SD* impact velocity ($p = .105$) and *SD* putter face angle at impact ($p =$

262 .425) were not significantly associated with putting proficiency early in practice. The total
263 effect of MS-C on putting proficiency became non-significant when the mediators were
264 included in the model signifying that mediation occurred. Bias corrected (BC) bootstrap CI's
265 indicated that the total indirect effect of MS-C on putting proficiency was significant, 95% CI
266 = 0.01 to 0.54, signifying that taken together *SD* impact velocity and *SD* putter face angle at
267 impact significantly mediated the impact of MS-C on putting proficiency. The specific
268 indirect effects of *SD* impact velocity, 95% CI = -0.01 to 0.74, and *SD* putter face angle at
269 impact, 95% CI = -0.07 to 0.52 were not significant. Given that *SD* impact velocity and *SD*
270 putter face angle at impact were highly correlated ($r = .745, p < .001$) early in practice it is
271 possible that collinearity may have attenuated the effects of the separate mediators (Preacher
& Hayes, 2008).

273 Figure 1b displays the unstandardized regression coefficients of the mediation model
274 for predicting the impact of CMP on putting proficiency early in practice via variability of the
275 stroke parameters. As can be seen in Figure 1b, CMP was significantly associated with *SD*
276 impact velocity ($p = .019$) and *SD* putter face angle at impact ($p = .047$). The effect of *SD*
277 impact velocity on putting proficiency approached significance ($p = .055$) and the effect of
278 *SD* putter face angle at impact was not significant ($p = .518$). The total effect of CMP on
279 putting proficiency approached significance ($p = .065$) and was not significant once the
280 mediators were including in the model ($p = .614$). BC bootstrap CI's indicated that the total
281 indirect effect of CMP on putting proficiency was significant, 95% CI = 0.01 to 0.73,
282 signifying that taken together *SD* impact velocity and *SD* putter face angle at impact
283 significantly mediated the impact of CMP on putting proficiency. The specific indirect effect
284 of *SD* impact velocity was significant, 95% CI = 0.01 to 0.91, but the specific indirect effect
285 of *SD* putter face angle at impact was not significant, 95% CI = -0.11 to 0.66.

Figure 2a and Figure 2b near here

287 Figure 2a displays the unstandardized regression coefficients of the mediation model
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5 289 the stroke parameters. As can be seen in Figure 2a, MS-C was significantly associated with
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7 290 *SD* impact velocity ($p = .022$) such that higher scores on MS-C were associated with less
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9 291 variable impact velocity, but MS-C was not significantly associated with *SD* putter face angle
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11 292 at impact ($p = .086$). *SD* impact velocity was significantly associated with putting proficiency
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13 293 ($p = .004$) but *SD* putter face angle at impact ($p = .425$) was not. The total effect of MS-C on
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15 294 putting proficiency became non-significant when the mediators were included in the model
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17 295 indicating that mediation occurred. BC bootstrap CI's indicated that the total indirect effect
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19 296 of MS-C was significant, 95% CI = 0.05 to 0.39, signifying that taken together *SD* impact
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21 297 velocity and *SD* putter face angle at impact significantly mediated the impact of MS-C on
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23 298 putting proficiency. The specific indirect effect of *SD* impact velocity was significant, 95%
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25 299 CI = 0.07 to 0.40, but the specific indirect effect of *SD* putter face angle at impact was not
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27 300 significant, 95% CI = -0.11 to 0.11.
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301 Figure 2b displays the unstandardized regression coefficients of the mediation model
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35 302 for predicting the impact of CMP on putting proficiency later in practice via variability of the
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37 303 stroke parameters. As can be seen in Figure 2b, CMP was significantly associated with *SD*
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39 304 putter face angle at impact ($p = .004$) but not with *SD* impact velocity ($p = .391$). *SD* impact
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41 305 velocity was significantly associated with putting proficiency ($p = .001$) but *SD* putter face
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43 306 angle at impact ($p = .718$) was not. The total and direct effects were not significant (p 's
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45 307 $>.05$). BC bootstrap CI's revealed no significant results for the total indirect effect, 95% CI =
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47 308 -0.09 to 0.46, and the specific indirect effects of *SD* impact velocity, 95% CI = -0.10 to 0.37,
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49 309 and *SD* putter face angle at impact, 95% CI = -0.09 to 0.29, were also not significant.
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310 Discussion

311 The current study investigated the role of the two dimensions of movement-specific
312 reinvestment in practicing a complex golf putting task (multiple degrees of freedom) and
313 explored the underlying kinematic mechanisms that underpin the influence of the two
314 dimensions of movement-specific reinvestment on performance. Reinvestment has generally
315 been viewed in a negative light but recently this view has been challenged by researchers
316 who suggest that in certain circumstances (e.g., during practice, skill refinement)
317 reinvestment might benefit performance (Carson et al., 2014; Toner & Moran, 2014b).

318 Conscious Motor Processing

319 Golf putting like the complex cross-handed laparoscopy task was expected to evoke
320 conscious motor processing, especially early in practice when participants were expected to
321 be consciously searching for optimal motor solutions to reduce errors. Moreover, we
322 predicted that a higher propensity for conscious motor processing would likely facilitate the
323 search for appropriate motor solutions via hypothesis testing behaviors, indicated by greater
324 variability of impact velocity and putter face angle at impact. Mediation analysis revealed
325 that a higher propensity for conscious motor processing positively influenced performance
326 early in practice by specifically reducing variability of impact velocity and putter face angle
327 at impact. It is possible that a high propensity to engage conscious control mechanisms (i.e.,
328 conscious motor processing) facilitated the search for motor solutions (Baddeley & Wilson,
329 1994; Gentile, 1998) early in practice.

330 It is unclear why a higher propensity for conscious motor processing resulted in lower
331 as opposed to higher variability of impact velocity and putter face angle at impact.

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332 Fundamentally, there are two types of error when putting from short distances on a flat
333 surface, ball speed (impact velocity) and ball direction (putter face angle at impact). Errors
334 related to impact velocity can result in putts being overshoot or undershot whereas errors
335 related to putter face angle at impact can result in putts being pushed or pulled wide of the
336 hole. It is possible that individuals with a higher propensity for conscious motor processing
337 were quicker at identifying the significance of impact velocity and putter face angle, and
338 endeavored to control these parameters, thus reducing variability across trials. The items of
339 the conscious motor processing subscale of the MSRS reflect a tendency to be ‘aware of the
340 way one’s body works’ and to ‘figure out why one’s actions fail’, suggesting that high scorers
341 on this subscale of the MSRS would be more in tune with adapting movements to achieve
342 success.

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343 Later in practice, when appropriate motor solutions should have been well-established
344 and when errors were fewer, conscious control mechanisms were expected to be less involved
345 in motor processes thereby attenuating the impact of conscious motor processing on putting
346 proficiency. In line with our predictions, the findings revealed that conscious motor
347 processing was not associated directly or indirectly (via movement kinematics), with putting
348 proficiency. This study also assessed whether conscious motor processing would influence
349 change in performance as a consequence of learning (i.e., performance difference from a pre-
350 test to retention test). The absence of an association between conscious motor processing
351 score and improvements in putting proficiency does little to resolve the dispute about whether
352 consciously engaging in motor control during task-specific practice is beneficial to motor
353 learning. However, it should be noted that participants in the current study did not receive
354 guidance or instructions about how to putt. It is possible that this caused them to engage in

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355 unproductive hypothesis testing behaviors. Future studies should examine whether providing
356 some form of guidance (e.g., guided discovery learning) to participants might result in more
357 purposeful use of conscious control that facilitates learning.

358 Movement Self-Consciousness

359 The scarcity of literature on movement self-consciousness made it difficult to make concrete
360 predictions with respect to this dimension of movement-specific reinvestment. Our results
361 were somewhat consistent with the findings of Malhotra et al. (in press) in that movement
362 self-consciousness was associated with performance early and later in practice. Mediation
363 analysis revealed that movement self-consciousness positively influenced putting proficiency
364 by reducing the variability of impact velocity and putter face angle at impact. It is difficult to
365 comprehend how being self-conscious about movements or being concerned about the 'style'
366 of movement manifests in more proficient performance in practice. Given that conscious
367 motor processing and movement self-consciousness shared similar underlying mechanisms
368 by which they impacted putting proficiency (i.e., greater consistency in impact velocity and
369 putter face angle at impact), especially earlier in practice, movement self-consciousness
370 might represent awareness of movements with high scorers better able to utilize exteroceptive
371 (visual, auditory) and kinesthetic (tactile) feedback to assess the discrepancy between the
372 actual and desired state (Schmidt, 2008). In this case, the construct 'movement self-
373 consciousness' might require re-interpretation. The items on the movement self-
374 consciousness subscale like 'I sometimes have the feeling I am watching myself move' and
375 'If I see my reflection in a shop window, I will examine my movements' might depict a form
376 of conscious *monitoring* of movements wherein attention is directed to movements but not

1 377 necessarily with an intention to consciously intervene in motor processes as one might expect
2 378 with conscious motor processing.
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5 379 Theoretical Implications
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9 380 Previous researchers have drawn a conceptual distinction between conscious (explicit)
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11 381 *monitoring* and conscious *control* of movements (Jackson et al., 2006; Masters & Maxwell,
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13 382 2008) and recent research has found that conscious monitoring and conscious control
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15 383 differentially influenced the kinematics of putting strokes and putting performance (Toner &
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17 384 Moran, 2011). Jackson et al. (2006) when discussing the breakdown of well-practiced skills
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19 385 argued that “it is possible that explicit monitoring has a general disruptive effect on motor
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21 386 performance and that additional disruption occurs when performers attempt to apply explicit
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23 387 rules to *control* as well as monitor their movements” (p. 64). That is, certain performance
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25 388 contexts (e.g., increased psychological pressure) may encourage individuals to transition
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27 389 from simply *monitoring* movements to consciously *controlling* them, resulting in further
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29 390 debilitation of well-practiced skills.
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36 391 Explicit monitoring studies involve instructions that direct the focus of attention
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38 392 towards a key aspect of the skill, for example, Beilock et al. (2002) asked skilled and less-
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40 393 skilled players to “*monitor* the swing of their [golf] club” (p. 8) or to “*attend* to the side of
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42 394 their foot that was in contact with the [soccer] ball” (p. 11). These instructions had a
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44 395 detrimental effect on skilled performers but Beilock et al. (2002) do not explain how
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46 396 disruption of motor processes can occur simply by ‘*monitoring*’ movements without at least
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48 397 some degree of conscious control (Masters & Maxwell, 2008). There is some evidence that
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50 398 implies that explicit monitoring does indeed involve an element of conscious control. For
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52 399 instance, Gray (2004) revealed that expert baseball players’ that monitored an aspect of the
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1 400 baseball swing experienced a disruption in performance which was partially attributed to an
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3 401 interference in the sequencing and timing of the movements involved in the baseball swing.
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5 402 Thus, performance disruptions due to explicit monitoring seem to be explained to some
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7 403 extent by conscious control mechanisms. Although, the conceptual distinction between
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9 404 monitoring and control is a valid one, (explicit) monitoring as currently defined in the
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11 405 literature needs to be re-assessed. Jackson et al. (2006) suggested that rather than consider
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13 406 explicit monitoring to be a discreet state it might be considered a continuum. Similarly, rather
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15 407 than being dichotomous states, *monitoring* and *control* should perhaps be considered as lying
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17 408 on a continuum, with the latter representing a greater degree of conscious control than the
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19 409 former. Following this line of reasoning, we propose that movement self-consciousness
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21 410 should be considered as a form of conscious monitoring and conscious motor processing
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23 411 should be considered as a form of conscious control. Such a clarification might help resolve
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25 412 some outstanding issues with respect to monitoring and control.
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32 413 First, if conscious monitoring is found to be independently associated with motor
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34 414 performance, the underlying mechanisms by which monitoring exerts its influence require
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36 415 empirical investigation. The findings of the current study suggest that conscious monitoring
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38 416 (a.k.a. movement self-consciousness) and control (a.k.a. conscious motor processing) seem to
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40 417 share some underlying kinematic processes by which they influence performance but an
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42 418 assessment of other psychological, physiological and neuropsychological measures might
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44 419 provide better insight into the unique processes underpinning monitoring and control.
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49 420 Second, it is unclear which factors might evoke a transition from simply monitoring to
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51 421 consciously controlling movements. If movement self-consciousness is considered to be a
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53 422 form of conscious monitoring, the findings of Malhotra et al. (in press) and the current study
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55 423 suggest that the complexity of the task might determine when a transition from conscious
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1 424 monitoring to control occurs. Malhotra et al. (in press) revealed that for less complex tasks
2 425 like the fundamental laparoscopic skill, which involved few degrees of freedom of
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4 426 movement, movement self-consciousness alone influenced performance, suggesting that
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7 427 conscious monitoring rather than control played a more salient role. Additionally, the
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10 428 findings of the current study suggest that early in practice, performance of a complex golf
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12 429 putting task that involves multiple degrees of freedom of movement was influenced by a
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14 430 propensity for movement self-consciousness and conscious motor processing, suggesting that
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17 431 both conscious monitoring and control played salient roles in performance.
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19 432 The extent to which the task proves demanding might also determine whether
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22 433 monitoring or control influence performance. Our findings suggest that early in practice when
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24 434 skill execution is difficult, movement self-consciousness and conscious motor processing
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27 435 tend to influence performance, suggesting that along with monitoring an element of
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29 436 conscious control is necessary to aid performance. Later in practice, when skills are well-
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32 437 learned and skill execution is not as demanding, simply monitoring movements may be
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34 438 adequate. Situations that significantly increase task complexity, such as the cross-handed
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36 439 laparoscopic task employed by Malhotra et al. (in press), seem also to evoke conscious
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39 440 control (i.e., conscious motor processing). Evidence for this can also be found in people with
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41 441 movement disorders, who often struggle with the demands of carrying out fundamental
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44 442 movement skills (Masters et al., 2007; Orrell et al., 2009; Wong et al., 2008). For Parkinson's
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46 443 disease patients, for example, conscious motor processing rather than movement self-
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49 444 consciousness plays a dominant role in motor performance (Masters et al., 2007). It appears
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51 445 that Parkinson's disease patients do not have the luxury to consciously monitor their '*style*' of
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54 446 movement but rather have to adopt conscious control strategies to ensure effective motor
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56 447 output.
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448 Considering movement self-consciousness and conscious motor processing as forms
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2 449 of conscious monitoring and conscious control, respectively, does appear to clarify some
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5 450 unresolved issues associated with monitoring and control. However, both dimensions of
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7 451 movement-specific reinvestment are likely to involve some degree of conscious control.
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10 452 There are other possible explanations for what *true* monitoring (without control) might
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12 453 signify. For instance, the flow state, a heightened state of concentration that results in
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14 454 complete absorption in an activity, might involve *true* monitoring of movements
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17 455 (Csikszentmihalyi, 1990). Loss of self-consciousness is one of the main factors associated
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19 456 with the flow experience such that performers are no longer concerned with how they appear
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22 457 to others but continue to be aware of their body, the process and movement itself (Jackson &
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24 458 Csikszentmihalyi, 1999, p. 66). Future work needs to more clearly define what conscious
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27 459 monitoring might entail in order to understand how it influences performance. For instance,
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29 460 techniques such as stimulated recall interviews (Bernier, Codron, Thienot, & Fournier, 2011)
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31 461 might help clarify what exact aspects of movement individuals attend to during conscious
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34 462 monitoring. There seems to be a possibility that movement self-consciousness is
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37 463 representative of something more than simply being self-conscious about movements. The
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39 464 current study answers some questions about how movement self-consciousness influences
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41 465 performance, however, it raises further questions about other underlying processes that
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44 466 underpin its unique influence on performance.

467 Although this study adds a new dimension to our understanding of reinvestment, the
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49 468 findings should be interpreted with caution. The study used trait rather than state measures of
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51 469 conscious motor processing and movement self-consciousness, making it difficult to ascertain
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54 470 what participants were doing while performing the task. Future studies should adopt and
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56 471 validate more reliable state measures of movement-specific reinvestment. Measures of brain

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472 activity, such as EEG coherence between the verbal analytical and motor planning regions of
473 the brain during motor performance, provide a strong departure point for this (e.g., EEG,
474 Hatfield, Haufler, Hung, & Spalding, 2004; Zhu et al., 2011).

475 Conclusion

476 Overall, our findings imply that movement self-consciousness and conscious motor
477 processing may benefit performance, especially earlier in practice. These results are
478 congruent with previous research, which suggests that directing conscious attention to
479 movements does not necessarily impair performance of less-practiced skills (Beilock et al.,
480 2002; Beilock & Gray, 2012; Ford et al., 2005; Gray, 2004). However it is important to note
481 that the accrual of knowledge as a result of reinvestment could potentially disrupt automated
482 skill execution later in practice. In particular, for performance of skills that are at least
483 partially automated conscious motor processing might be detrimental (Masters & Maxwell,
484 2008). Future studies are required to determine how the two dimensions interact to influence
485 skilled performance in extremely demanding environments that raise psychological pressure.

486 Prior research has advocated implicit modes of learning to guard against the potential
487 adverse effects of reinvestment under pressure (e.g., Masters, 1992), especially for well-
488 practiced skills. However, recently researchers have challenged the increasing ubiquitous
489 viewpoint that reinvestment is necessarily detrimental to performance of well-practiced skills.
490 Toner and Moran (2014b) argued that exponents of self-focused attention theories examine
491 performance in isolated instances and often fail to consider changes in attention processes
492 across time (e.g., on and off season) and contingencies (e.g., skill recovery after injury).
493 Future work should move beyond examining ‘static snapshots’ (p. 4, Toner & Moran, 2014b)
494 and instead employ novel approaches (stimulated recall, Bernier et al., 2011) to examine the
495 complex and dynamic ways in which consciousness might contribute to skill execution.

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Table 1.
Descriptive data and correlation coefficients between MS-C, CMP, putting proficiency and *SD*'s of impact velocity and putter face angle at impact

		<i>M</i>	<i>SD</i>	1	2	3	4	5	6	7	8	9	10
1	MS-C	20.10	3.85	-									
2	CMP	20.47	4.02	.58**									
	<u>Early-Practice</u>												
3	Putting proficiency	9.00	4.60	.50**	.34	-							
4	<i>SD</i> impact velocity	136.25	66.83	-.39*	-.43*	-.62**	-						
5	<i>SD</i> putter face angle at impact	1.72	0.55	-.27	-.37*	-.53**	.75**						
	<u>Later-Practice</u>												
6	Putting proficiency	13.63	3.37	.53**	.15	.46*	-.26	-.33	-				
7	<i>SD</i> impact velocity	77.24	24.15	-.42*	-.16	-.54**	.64**	.35	-.63**	-			
8	<i>SD</i> putter face angle at impact	1.31	0.37	-.32	-.51**	-.36*	.47**	.53**	-.23	.26			
	<u>Change From Pre-Test to Retention Test</u>												
9	Δ Putting proficiency	3.03	2.5	.18	.01	-.19	.29	.39*	.19	.12	.10	-	
10	Δ <i>SD</i> impact velocity	184.24	179.53	.42*	.34	.15	-.42*	-.25	.23	-.30	-.28	.05	-
11	Δ <i>SD</i> putter face angle at impact	-1.01	1.32	.03	-.01	-.12	.10	-.24	-.01	.10	-.12	-.21	.24

*** $p < .001$, ** $p < .01$, * $p < .05$
MS-C, movement self-consciousness; CMP, conscious motor processing

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28 **Figure Legends**

29 Figure 1 Mediation models for early-practice illustrating the impact of MS-C (panel a) and
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Figure 1a
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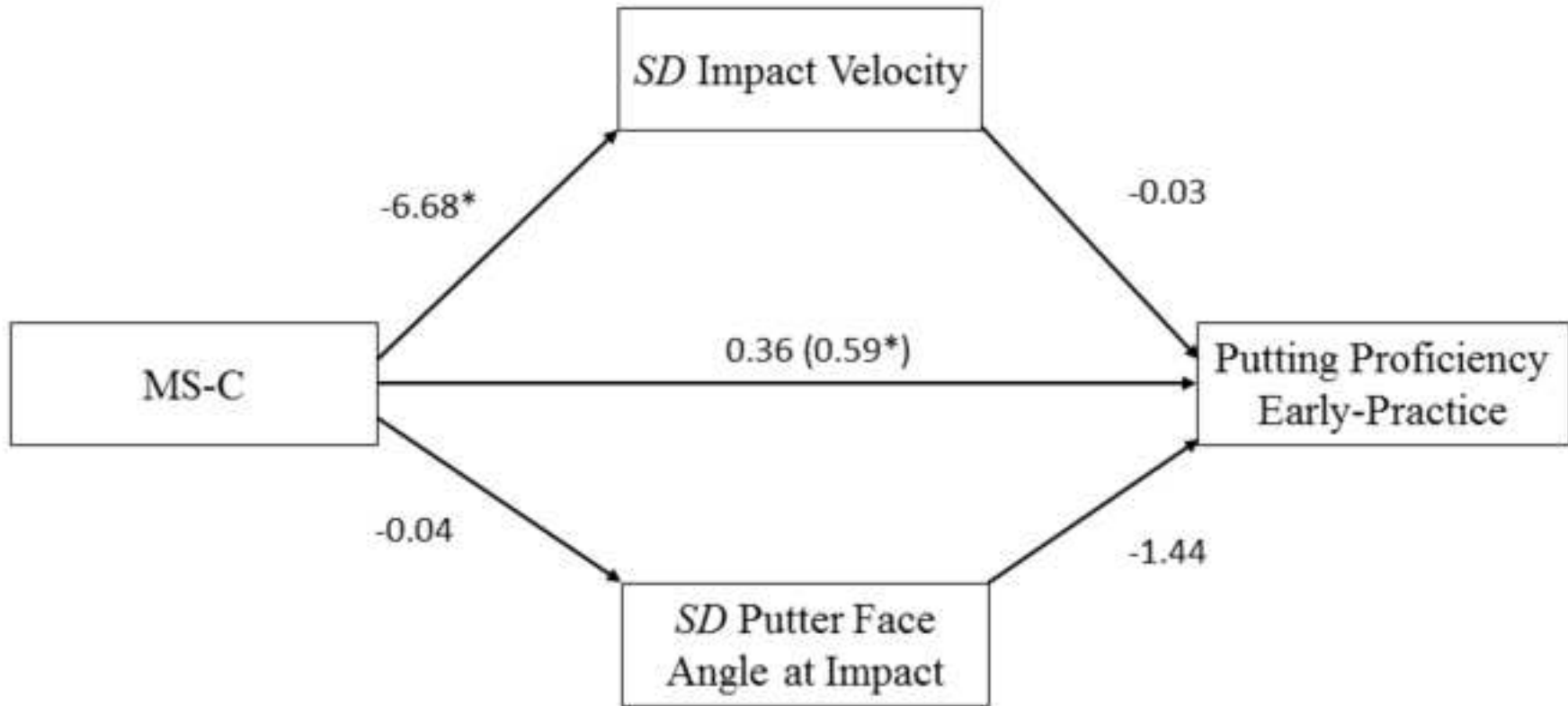


Figure 1b
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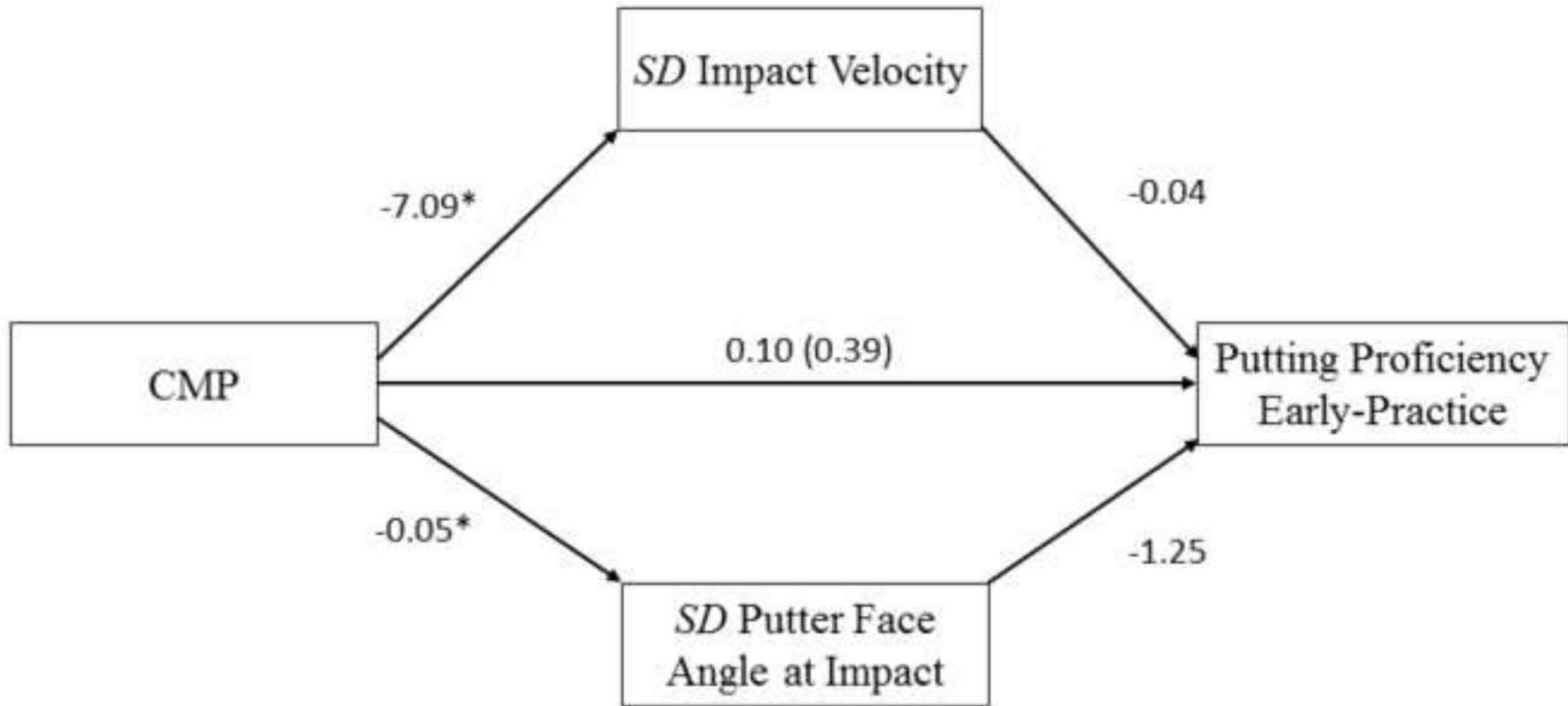


Figure 2a
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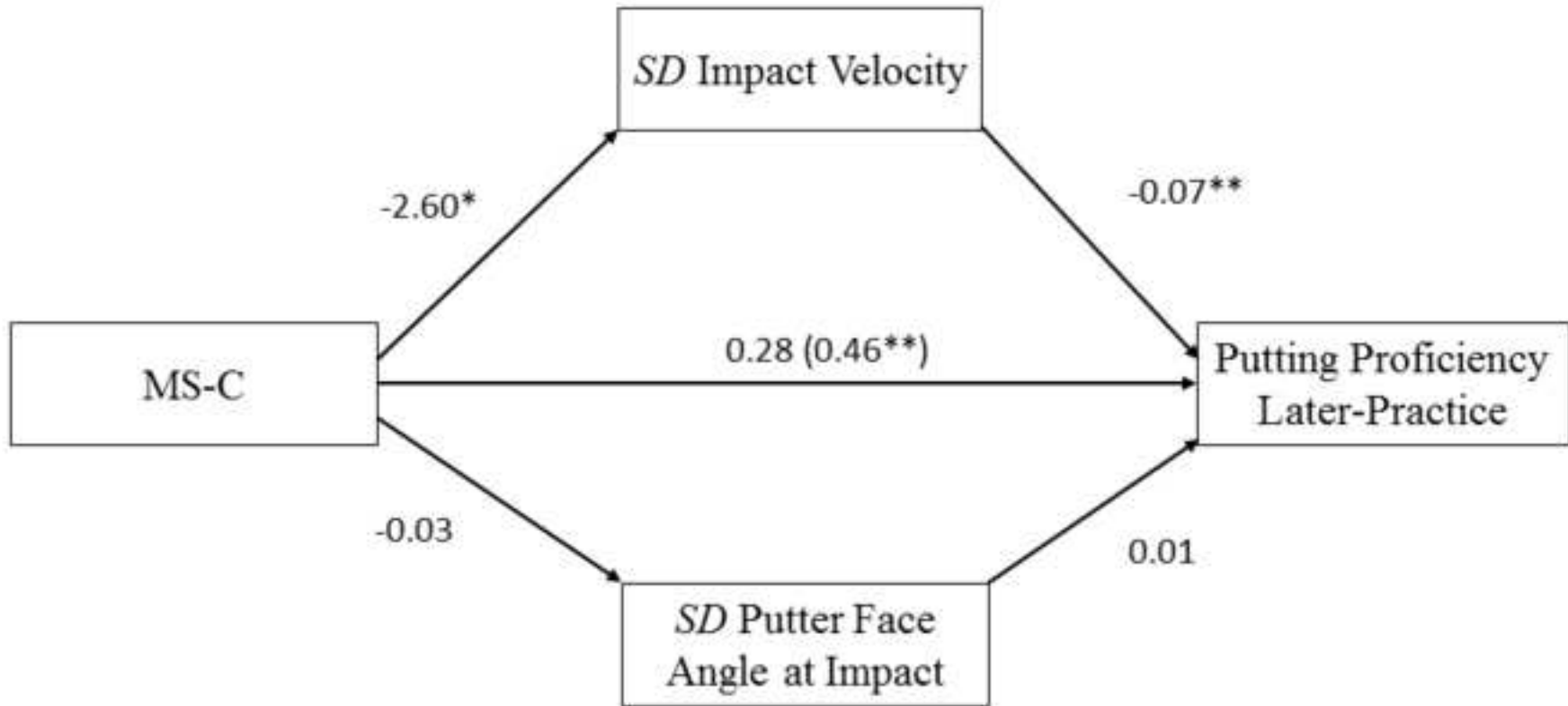


Figure 2b
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