Original Article

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

Neha Malhotra[1*§], Jamie M Poolton[1*], Mark R Wilson[2*] Sadahiro Omuro[1*]

& Rich SW Masters[1, 3*]

[1] Institute of Human Performance, University of Hong Kong, Hong Kong
[2] School of Sport and Health Sciences, College of Life and Environmental Sciences, University of Exeter, UK

[3] Department of Sport and Leisure Studies, University of Waikato, New Zealand

*These authors contributed equally to this work
§ Corresponding author

Corresponding Author:

Neha Malhotra
Institute of Human Performance
3/F, The Hong Kong Jockey Club Building for Interdisciplinary Research
5 Sassoon Road,
Pokfulam,
Hong Kong

Tel: +852 28315282
Fax: +852 28551712
nehamal@hku.hk

Acknowledgments

This work was supported by a GRF grant from the Research Grants Council, University Grants Committee, Hong Kong (HKU752211H).

Introduction

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

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

The pervasive view that conscious engagement in online skill execution (reinvestment) necessarily hinders performance has recently been challenged by researchers who have suggested that consciousness might be useful in certain circumstances (Toner & Moran, 2014a, 2014b). For instance, when well-learned techniques need to be subtly changed or *refined*, reinvestment might prove advantageous for performance (Carson, Collins, & Richards, 2014; Toner & Moran, 2014b). For example, consciously monitoring movements might help skilled performers to identify aspects of their movements that are in need of refinement and conscious control might help when refining those movements. Additionally, for novices it is possible that reinvestment early in practice may facilitate the identification of appropriate solutions to the motor problem (Baddeley & Wilson, 1994; Berry & Broadbent, 1988; Gentile, 1998).

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

Prior research has also revealed that although directing conscious attention to movements is debilitative during performance of well-practiced skills, it might not be debilitative during performance of less-practiced skills (Beilock, Carr, MacMahon, & Starkes, 2002; Beilock & Gray, 2012; Ford, Williams, & Hodges, 2005; Gray, 2004). Individuals with a high propensity for reinvestment (high reinvestors) might be more inclined to engage in hypothesis testing behavior, which might initially lead to inconsistencies in the pattern and parameterization of movement; however, it should lead to the identification of effective actions earlier in practice. For example, a novice golfer who is a high reinvestor might start off making several technical adjustments in force and/or angle of the putter face at ball impact, leading to fluctuations in performance outcome, but should be quicker at determining the optimal kinematics of putting stroke than a low reinvestor. Following this line of reasoning, high reinvestors might have an advantage early in practice. However, later in practice, when novice golfers should have figured out appropriate motor solutions (e.g., correct force to hit the ball), reinvestment should no longer support performance.

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

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

Technological advancements have equipped researchers with the means to capture the involvement of underlying mechanisms of movement-specific reinvestment on motor performance. For instance, Cooke, Kavussanu, McIntyre, Boardley, and Ring (2011), recently provided some insight into the underlying kinematic processes that are linked to conscious motor processing. In their study, expert golfers’ performance was assessed under low-, medium- and high-pressure conditions. Expert golfers tended to perform better and displayed lower levels of conscious motor processing under medium as opposed to high- and low-pressure conditions. More importantly, the study revealed subtle links between the propensity for conscious motor processing and the kinematics of movements, with lower levels of conscious motor processing in the medium-pressure condition accompanied by lower impact velocities, and slower less jerky swings.

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

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

The primary aim of the current study was therefore to investigate the unique influence of the two dimensions of movement-specific reinvestment on performance of a complex motor skill (a golf putt) early and later in practice and to examine the underlying movement kinematics that might mediate the role of the two dimensions in putting proficiency. Given that the direction and magnitude of force applied to the ball by the putter face are the two main factors that ultimately determine putt success, appropriate kinematic measures were selected (Pelz, 2000; Sim & Kim, 2010). Variability of impact velocity was measured to assess force applied to the ball. Prior research has identified 3 main parameters that determine direction of the putting stroke; with putter face angle at impact being the most important determinant (80%), followed by putter path (17%) and horizontal impact point (3%) (Karlsen, Smith, & Nilsson, 2008). Given that variability of the putter face angle (in degrees) at ball impact (relative to the direction of aim) has been shown to be the most important parameter that determines stroke direction it was used in the current study (Karlsen et al., 2008; Pelz, 2000). We expected that the complexity of the task would encourage individuals with a high propensity for conscious motor processing to engage in hypothesis testing behavior which would be reflected in a positive association between this dimension and variability of impact velocity and putter face angle at impact. We were uncertain whether conscious engagement in the task would immediately manifest in more proficient putting early in practice. We expected any association between conscious motor processing and putting early in practice to have weakened later in practice as individuals become less consciously involved in the control of movement. A secondary aim of the study was to assess whether the two dimensions of movement-specific reinvestment influenced change in performance as a consequence of learning (i.e., performance difference from a pre-test to retention test). It was unclear whether the tendency to consciously engage in motor control would be beneficial (e.g., Gentile, 1998) or detrimental to learning. The relative paucity of literature on the role of movement self-consciousness during practice prevented us from making empirically based predictions about its influence.

Methods

Participants

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

Apparatus

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

Measures

Participants were required to complete the Movement Specific Reinvestment Scale (MSRS) in the week prior to attending the experiment. At this point, participants were unaware of the 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.

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

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

Procedure

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

Data analysis

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

Mediation analyses were conducted to examine the indirect effects of multiple mediators (i.e., *SD* impact velocity and *SD* putter face angle at impact) on the influence of MS-C and CMP on putting proficiency. Mediation analysis was conducted using the PROCESS custom dialog developed by Hayes (2013) which estimates indirect effects using a non-parametric bootstrapping method. Bootstrapping is a computationally rigorous re-sampling procedure that is highly recommended especially for testing mediation in small sample sizes (Cerin, Taylor, Leslie, & Owen, 2006) . PROCESS uses percentile bootstrap confidence intervals and bias corrected bootstrap confidence intervals[3] to estimate the total, direct and indirect effects of the independent variable on the dependent variable via multiple mediators. Mediation can be inferred when the bootstrap confidence intervals of the indirect 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).

Results

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

Descriptive Statistics

Table 1 provides the descriptive data and Pearson's product moment correlations of all variables. Early in practice, MS-C scores (p = .036) were negatively correlated with *SD* impact velocity as were CMP scores (p = .019). CMP was also negatively correlated with *SD* putter face angle at impact (p = .047). Lower variability of impact velocity (p < .001) and putter face angle at impact (p = .002) was associated with higher putting proficiency. Early in practice, MS-C was positively correlated with putting proficiency (p = .005) and there was a trend for a similar association with CMP (p = .065). Later in practice, MS-C scores were negatively correlated with *SD* impact velocity (p = .022) and CMP scores were negatively correlated with *SD* putter face angle at impact (p = .004). Lower variability of impact velocity was associated with higher putting proficiency (p < .001) but variability of putter face angle at impact was not significantly correlated with putting proficiency (p = .223). MS-C was positively correlated with putting proficiency (p = .003) but CMP was not (p = .442). MS-C (p = .024) was significantly correlated with change in SD impact velocity and CMP approached significance (p =.069); higher scores on MS-C and CMP were associated with less change in *SD* impact velocity from pre-test to retention test. MS-C and CMP were not significantly correlated with change in putting proficiency and change in *SD* putter face angle at impact (p's > .05).

Mediation

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

Figure 1 a and Figure 1b near here

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

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

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

Figure 2a and Figure 2b near here

Figure 2a displays the unstandardized regression coefficients of the mediation model for predicting the impact of MS-C on putting proficiency later in practice via variability of the stroke parameters. As can be seen in Figure 2a, MS-C was significantly associated with *SD* impact velocity (p = .022) such that higher scores on MS-C were associated with less variable impact velocity, but MS-C was not significantly associated with *SD* putter face angle at impact (p = .086). *SD* impact velocity was significantly associated with putting proficiency (p = .004) but *SD* putter face angle at impact (p = .425) was not. The total effect of MS-C on putting proficiency became non-significant when the mediators were included in the model indicating that mediation occurred. BC bootstrap CI's indicated that the total indirect effect of MS-C was significant, 95% CI = 0.05 to 0.39, signifying that taken together *SD* impact velocity and *SD* putter face angle at impact significantly mediated the impact of MS-C on putting proficiency. The specific indirect effect of *SD* impact velocity was significant, 95% CI = 0.07 to 0.40, but the specific indirect effect of *SD* putter face angle at impact was not significant, 95% CI = -0.11 to 0.11.

Figure 2b displays the unstandardized regression coefficients of the mediation model for predicting the impact of CMP on putting proficiency later in practice via variability of the stroke parameters. As can be seen in Figure 2b, CMP was significantly associated with *SD* putter face angle at impact (p = .004) but not with *SD* impact velocity (p =.391). *SD* impact velocity was significantly associated with putting proficiency (p = .001) but *SD* putter face angle at impact (p = .718) was not. The total and direct effects were not significant (p's >.05). BC bootstrap CI's revealed no significant results for the total indirect effect, 95% CI = -0.09 to 0.46, and the specific indirect effects of *SD* impact velocity, 95% CI = -0.10 to 0.37, and *SD* putter face angle at impact, 95% CI = -0.09 to 0.29, were also not significant.

Discussion

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

Conscious Motor Processing

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

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

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

Later in practice, when appropriate motor solutions should have been well-established and when errors were fewer, conscious control mechanisms were expected to be less involved in motor processes thereby attenuating the impact of conscious motor processing on putting proficiency. In line with our predictions, the findings revealed that conscious motor processing was not associated directly or indirectly (via movement kinematics), with putting proficiency. This study also assessed whether conscious motor processing would influence change in performance as a consequence of learning (i.e., performance difference from a pre-test to retention test). The absence of an association between conscious motor processing score and improvements in putting proficiency does little to resolve the dispute about whether consciously engaging in motor control during task-specific practice is beneficial to motor learning. However, it should be noted that participants in the current study did not receive guidance or instructions about how to putt. It is possible that this caused them to engage in unproductive hypothesis testing behaviors. Future studies should examine whether providing some form of guidance (e.g., guided discovery learning) to participants might result in more purposeful use of conscious control that facilitates learning.

Movement Self-Consciousness

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

Theoretical Implications

Previous researchers have drawn a conceptual distinction between conscious (explicit) *monitoring* and conscious *control* of movements (Jackson et al., 2006; Masters & Maxwell, 2008) and recent research has found that conscious monitoring and conscious control differentially influenced the kinematics of putting strokes and putting performance (Toner & Moran, 2011). Jackson et al. (2006) when discussing the breakdown of well-practiced skills argued that "it is possible that explicit monitoring has a general disruptive effect on motor performance and that additional disruption occurs when performers attempt to apply explicit rules to *control* as well as monitor their movements" (p. 64). That is, certain performance contexts (e.g., increased psychological pressure) may encourage individuals to transition from simply *monitoring* movements to consciously *controlling* them, resulting in further debilitation of well-practiced skills.

Explicit monitoring studies involve instructions that direct the focus of attention towards a key aspect of the skill, for example, Beilock et al. (2002) asked skilled and less-skilled players to "*monitor* the swing of their [golf] club" (p. 8) or to "*attend* to the side of their foot that was in contact with the [soccer] ball" (p. 11). These instructions had a detrimental effect on skilled performers but Beilock et al. (2002) do not explain how disruption of motor processes can occur simply by '*monitoring*' movements without at least some degree of conscious control (Masters & Maxwell, 2008). There is some evidence that implies that explicit monitoring does indeed involve an element of conscious control. For instance, Gray (2004) revealed that expert baseball players' that monitored an aspect of the baseball swing experienced a disruption in performance which was partially attributed to an interference in the sequencing and timing of the movements involved in the baseball swing. Thus, performance disruptions due to explicit monitoring seem to be explained to some extent by conscious control mechanisms. Although, the conceptual distinction between monitoring and control is a valid one, (explicit) monitoring as currently defined in the literature needs to be re-assessed. Jackson et al. (2006) suggested that rather than consider explicit monitoring to be a discreet state it might be considered a continuum. Similarly, rather than being dichotomous states, *monitoring* and *control* should perhaps be considered as lying on a continuum, with the latter representing a greater degree of conscious control than the former. Following this line of reasoning, we propose that movement self-consciousness should be considered as a form of conscious monitoring and conscious motor processing should be considered as a form of conscious control. Such a clarification might help resolve some outstanding issues with respect to monitoring and control.

First, if conscious monitoring is found to be independently associated with motor performance, the underlying mechanisms by which monitoring exerts its influence require empirical investigation. The findings of the current study suggest that conscious monitoring (a.k.a. movement self-consciousness) and control (a.k.a. conscious motor processing) seem to share some underlying kinematic processes by which they influence performance but an assessment of other psychological, physiological and neuropsychological measures might provide better insight into the unique processes underpinning monitoring and control.

Second, it is unclear which factors might evoke a transition from simply monitoring to consciously controlling movements. If movement self-consciousness is considered to be a form of conscious monitoring, the findings of Malhotra et al. (in press) and the current study suggest that the complexity of the task might determine when a transition from conscious monitoring to control occurs. Malhotra et al. (in press) revealed that for less complex tasks like the fundamental laparoscopic skill, which involved few degrees of freedom of movement, movement self-consciousness alone influenced performance, suggesting that conscious monitoring rather than control played a more salient role. Additionally, the findings of the current study suggest that early in practice, performance of a complex golf putting task that involves multiple degrees of freedom of movement was influenced by a propensity for movement self-consciousness and conscious motor processing, suggesting that both conscious monitoring and control played salient roles in performance.

The extent to which the task proves demanding might also determine whether monitoring or control influence performance. Our findings suggest that early in practice when skill execution is difficult, movement self-consciousness and conscious motor processing tend to influence performance, suggesting that along with monitoring an element of conscious control is necessary to aid performance. Later in practice, when skills are well-learned and skill execution is not as demanding, simply monitoring movements may be adequate. Situations that significantly increase task complexity, such as the cross-handed laparoscopic task employed by Malhotra et al. (in press), seem also to evoke conscious control (i.e., conscious motor processing). Evidence for this can also be found in people with movement disorders, who often struggle with the demands of carrying out fundamental movement skills (Masters et al., 2007; Orrell et al., 2009; Wong et al., 2008). For Parkinson's disease patients, for example, conscious motor processing rather than movement self-consciousness plays a dominant role in motor performance (Masters et al., 2007). It appears that Parkinson's disease patients do not have the luxury to consciously monitor their *'style'* of movement but rather have to adopt conscious control strategies to ensure effective motor output.

Considering movement self-consciousness and conscious motor processing as forms of conscious monitoring and conscious control, respectively, does appear to clarify some unresolved issues associated with monitoring and control. However, both dimensions of movement-specific reinvestment are likely to involve some degree of conscious control. There are other possible explanations for what *true* monitoring (without control) might signify. For instance, the flow state, a heightened state of concentration that results in complete absorption in an activity, might involve *true* monitoring of movements (Csikszentmihalyi, 1990). Loss of self-consciousness is one of the main factors associated with the flow experience such that performers are no longer concerned with how they appear to others but continue to be aware of their body, the process and movement itself (Jackson & Csikszentmihalyi, 1999, p. 66). Future work needs to more clearly define what conscious monitoring might entail in order to understand how it influences performance. For instance, techniques such as stimulated recall interviews (Bernier, Codron, Thienot, & Fournier, 2011) might help clarify what exact aspects of movement individuals attend to during conscious monitoring. There seems to be a possibility that movement self-consciousness is representative of something more than simply being self-conscious about movements. The current study answers some questions about how movement self-consciousness influences performance, however, it raises further questions about other underlying processes that underpin its unique influence on performance.

Although this study adds a new dimension to our understanding of reinvestment, the findings should be interpreted with caution. The study used trait rather than state measures of conscious motor processing and movement self-consciousness, making it difficult to ascertain what participants were doing while performing the task. Future studies should adopt and validate more reliable state measures of movement-specific reinvestment. Measures of brain activity, such as EEG coherence between the verbal analytical and motor planning regions of the brain during motor performance, provide a strong departure point for this (e.g., EEG, Hatfield, Haufler, Hung, & Spalding, 2004; Zhu et al., 2011).

Conclusion

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

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

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

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

References

Baddeley, A., & Wilson, B. A. (1994). When implicit learning fails: Amnesia and the problem of error elimination. *Neuropsychologia, 32*(1), 53-68.

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied, 8*(1), 6-16.

Beilock, S. L., & Gray, R. (2012). From attentional control to attentional spillover: A skill-level investigation of attention, movement, and performance outcomes. *Human Movement Science, 31*(6), 1473-1499.

Bernier, M., Codron, R., Thienot, E., & Fournier, J. F. (2011). The attentional focus of expert golfers in training and competition: A naturalistic investigation. *Journal of Applied Sport Psychology, 23*(3), 326-341.

Berry, D. C., & Broadbent, D. E. (1988). Interactive tasks and the implicit-explicit distinction. *British Journal of Psychology, 79*(2), 251-272.

Carson, H. J., Collins, D., & Richards, J. (2014). Intra-individual movement variability during skill transitions: A useful marker? *European Journal of Sport Science, 14*(4), 327-336.

Cerin, E., & MacKinnon, D. P. (2009). A commentary on current practice in mediating variable analyses in behavioural nutrition and physical activity. *Public Health Nutrition, 12*(8), 1182-1188.

Cerin, E., Taylor, L. M., Leslie, E., & Owen, N. (2006). Small-scale randomized controlled trials need more powerful methods of mediational analysis than the Baron–Kenny method. *Journal of Clinical Epidemiology, 59*(5), 457-464.

Chell, B. J., Graydon, J. K., Crowley, P. L., & Child, M. (2003). Manipulated stress and dispositional reinvestment in a wall-volley task: An investigation into controlled processing. *Perceptual and Motor Skills, 97*(2), 435-448.

Cooke, A., Kavussanu, M., McIntyre, D., Boardley, I. D., & Ring, C. (2011). Effects of competitive pressure on expert performance: Underlying psychological, physiological, and kinematic mechanisms. *Psychophysiology, 48*(8), 1146-1156.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper Perennial

Deikman, A. J. (1966). De-automatization and the Mystic Experience. *Psychiatry: Journal for the Study of Interpersonal Processes, 29*(4), 324-338.

Ford, P., Williams, A. M., & Hodges, N. J. (2005). Online attentional-focus manipulations in a soccer-dribbling task: Implications for the proceduralization of motor skills. *Journal of Motor Behavior, 37*(5), 386-394.

Gentile, A. M. (1998). Implicit and explicit processes during acquisition of functional skills. *Scandinavian Journal of Occupational Therapy, 5*(1), 7-16.

Gray, R. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking, and slumps. *Journal of Experimental Psychology: Applied, 10*(1), 42-54.

Hardy, L., Mullen, R., & Jones, G. (1996). Knowledge and conscious control of motor actions under stress. *British Journal of Psychology, 87*, 621-636.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in Psychology, 52*, 139-183.

Hatfield, B. D., Haufler, A. J., Hung, T.M., & Spalding, T. W. (2004). Electroencephalographic studies of skilled psychomotor performance. *Journal of Clinical Neurophysiology*, *21*(3), 144-156.

Hayes, A. F. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis : A Regression-Based Approach* Retrieved from http://HKUHK.eblib.com.au/patron/FullRecord.aspx?p=1186800

Jackson, R. C., Ashford, K. J., & Norsworthy, G. (2006). Attentional focus, dispositional reinvestment, and skilled motor performance under pressure. *Journal of Sport & Exercise Psychology*, *28*(1), 49-68.

Jackson, R. C., Kinrade, N. P., Hicks, T., & Wills, R. (2013). Individual propensity for reinvestment: Field-based evidence for the predictive validity of three scales. *International Journal of Sport Psychology*, *44*(4), 331-350.

Jackson, S. A., & Csikszentmihalyi, M. (1999). *Flow in sports*: Human Kinetics.

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

Land, W., & Tenenbaum, G. (2012). An outcome-and process-oriented examination of a golf-specific secondary task strategy to prevent choking under pressure. *Journal of Applied Sport Psychology*, *24*(3), 303-322.

MacKinnon, D. P., Krull, J. L., & Lockwood, C. M. (2000). Equivalence of the Mediation, Confounding and Suppression Effect. *Prevention Science*, *1*(4), 173-181.

Malhotra, N., Poolton, J. P., Wilson, M. R., Fan, J., & Masters, R. S. W. (in press). Conscious motor processing and movement self-consciousness: Two dimensions of personality that influence laparoscopic training. *Journal of Surgical Education*.

Masters, R. S. W. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown. *British Journal of Psychology, 83*(3), 343-358.

Masters, R. S. W. , Pall, H. S., MacMahon, K. M. A., & Eves, F. F. (2007). Duration of Parkinson disease is associated with an increased propensity for "reinvestment". *Neurorehabilitation and Neural Repair, 21*(2), 123-126.

Masters, R. S. W., Eves, F. F. , & Maxwell, J. P. (2005). Development of a movement specific Reinvestment Scale. In T. Morris, P. Terry, S. Gordon, S. Hanrahan, L. Ievleva, G. Kolt & T. P. (Eds.), *Proceedings of the ISSP 11th World Congress of Sport Psychology*. Sydney, Australia.

Masters, R. S. W., & Maxwell, J. P. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology, 1*(2), 160-183.

Masters, R. S. W., Polman, R. C. J., & Hammond, N. V. (1993). 'Reinvestment': A dimension of personality implicated in skill breakdown under pressure. *Personality and Individual Differences, 14*(5), 655-666.

Masters, R. S. W., & Poolton, J. P. (2012). Advances in implicit motor learning. In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research,theory and practice* (pp. 207-228). London: Routledge.

Maxwell, J. P., Masters, R. S. W., & Eves, F. F. (2000). From novice to no know-how: A longitudinal study of implicit motor learning. *Journal of Sports Sciences, 18*(2), 111-120.

Maxwell, J. P., Masters, R. S. W., & Poolton, J. M. (2006). Performance breakdown in sport: The roles of reinvestment and verbal knowledge. *Research Quarterly for Exercise and Sport, 77*(2), 271-276.

Orrell, A. J., Masters, R. S. W., & Eves, F. F. (2009). Reinvestment and movement disruption following stroke. *Neurorehabilitation and Neural Repair, 23*(2), 177-183.

Pelz, D. (2000). *David Pelz's Putting Bible*. New York: Doubleday.

Pijpers, J. R., Oudejans, R. R. D., Holsheimer, F., & Bakker, F. C. (2003). Anxiety–performance relationships in climbing: A process-oriented approach. *Psychology of Sport and Exercise, 4*(3), 283-304.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*(3), 879-891.

Schmidt, R. A. (2008). Sensory contributions to skilled performance. In R. A. Schmidt & C. A. Wrisberg (Eds.), *Motor learning and performance: A situation-based learning approach* (pp. 62-102). Champaign, IL: Human Kinetics.

Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods, 7*(4), 422-445.

Sim, M., & Kim, J. (2010). Differences between experts and novices in kinematics and accuracy of golf putting. *Human Movement Science, 29*(6), 932-946.

Toner, J., & Moran, A. (2011). The effects of conscious processing on golf putting proficiency and kinematics. *Journal of Sports Sciences, 29*(7), 673-683.

Toner, J., & Moran, A. (2014a). Enhancing performance proficiency at the expert level: Considering the role of 'somaesthetic awareness'. *Psychology of Sport and Exercise*.

Toner, J., & Moran, A. (2014b). In praise of conscious awareness: A new framework for the investigation of “continuous improvement” in expert athletes. *Frontiers in Psychology, 5*, 1-5.

Wong, W. L., Masters, R. S. W., Maxwell, J. P., & Abernethy, A. B. (2008). Reinvestment and falls in community-dwelling older adults. *Neurorehabilitation and Neural Repair, 22*(4), 410-414.

Zhu, F. F., Poolton, J. M., Wilson, M. R., Maxwell, J. P., & Masters, R. S. W. (2011). Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement. *Biological Psychology, 87*(1), 66-73.

Figure Legends

Figure 1 Mediation models for early-practice illustrating the impact of MS-C (panel a) and CMP (panel b) on putting proficiency via multiple mediators. Note. ***$p < .001$, **$p < .01$, * $p < .05$

Figure 2 Mediation models for later-practice illustrating the impact of MS-C (panel a) and CMP (panel b) on putting proficiency via multiple mediators. Note. ***$p < .001$, **$p < .01$, * $p < .05$

Figure 1a

Click here to download high resolution image

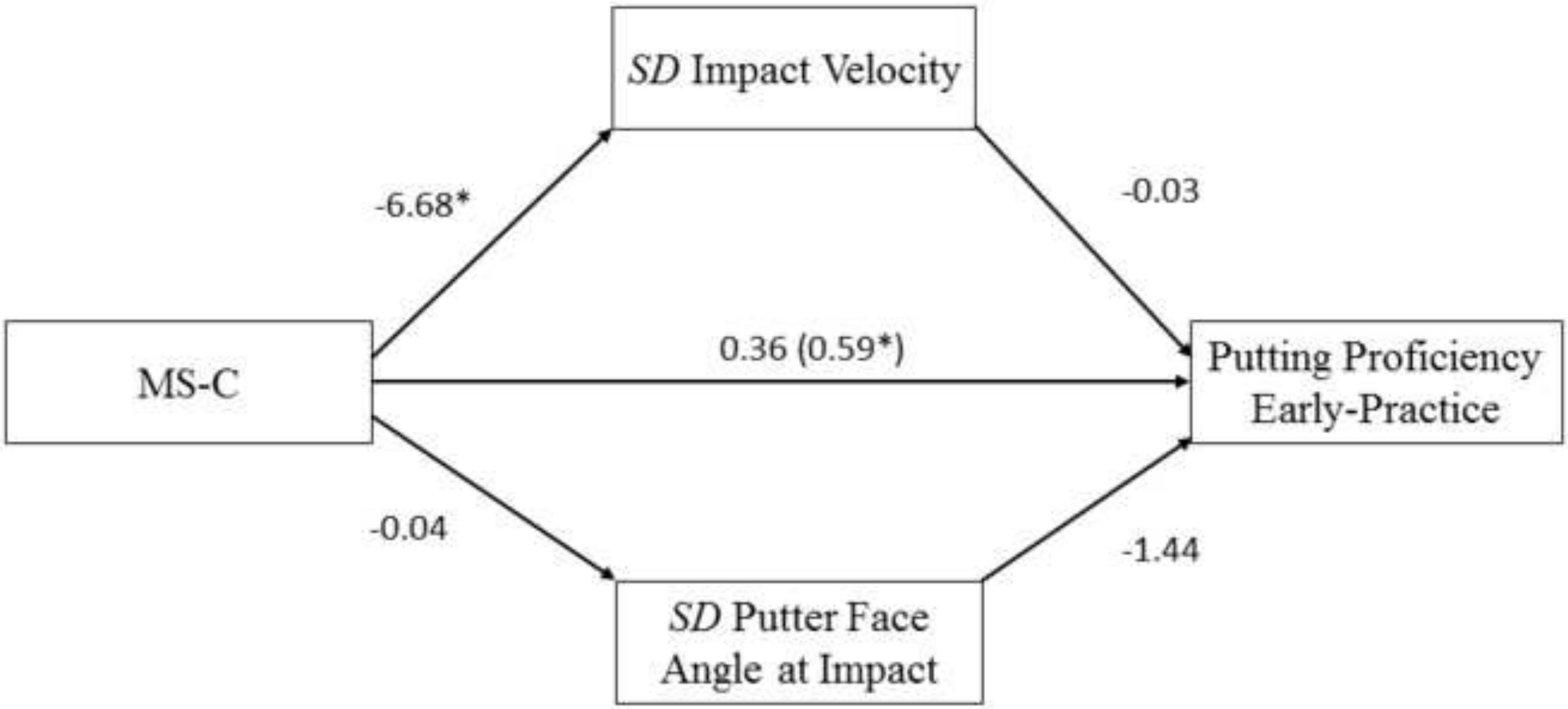

Figure 1b
Click here to download high resolution image

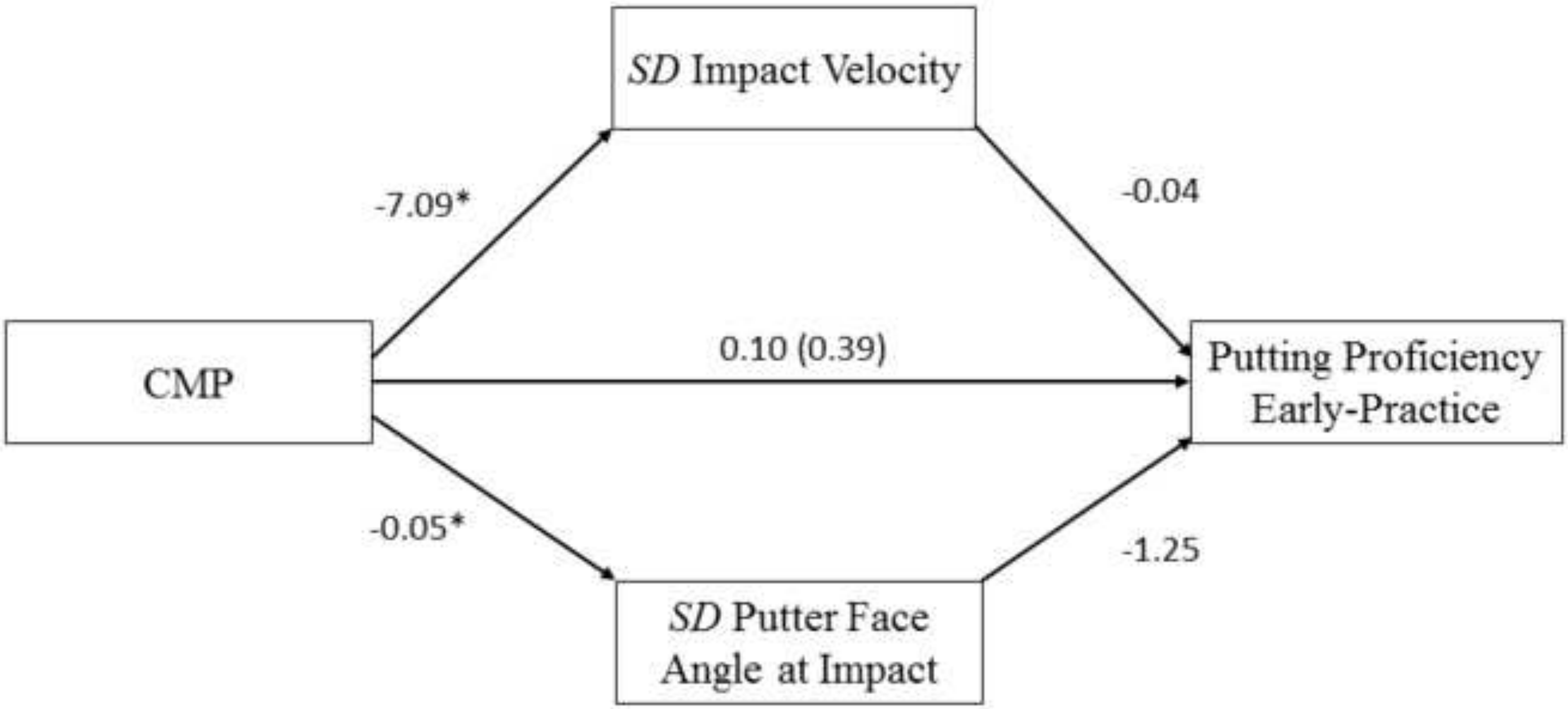

Figure 2a
Click here to download high resolution image

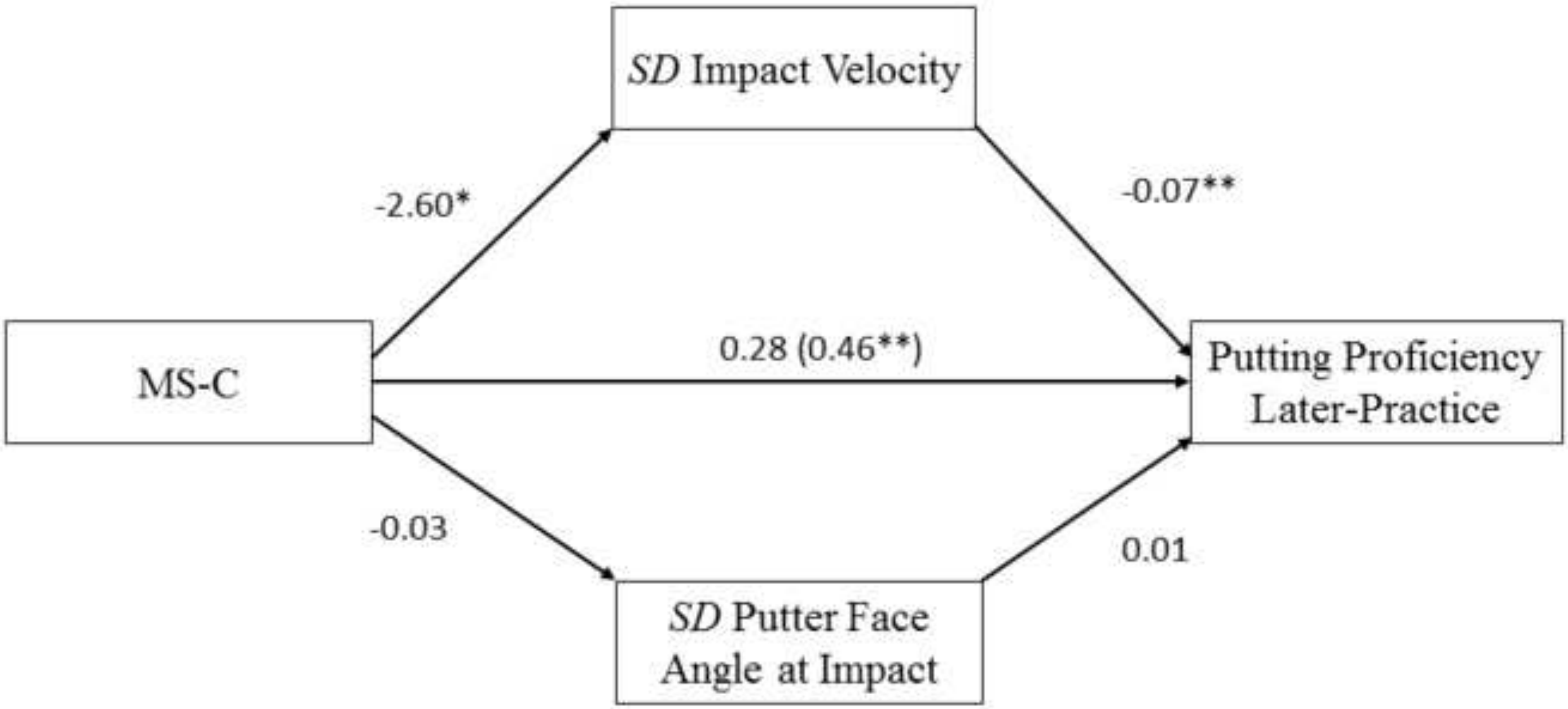

Figure 2b

Click here to download high resolution image