Automatization and deautomatization of perceptual-motor skills

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Chapter 4

Attention and time constraints in perceptual-motor learning and performance: Instruction, analogy, and skill level

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Abstract

In the present study we aimed to gain more insight into the effects of attention focus and time constraints on skill learning and performance in novices and experts by means of two complementary experiments. Experiment 1 showed that skill-focus conditions and slowed ball frequency disrupted the accuracy of experts, but dual-task conditions and speeded ball frequency did not. For novices, the effects were reversed. In Experiment 2, we extended these findings by instructing novices either explicitly or by analogy. Explicitly instructed novices were less accurate in skill-focused and dual-task conditions than in single-task conditions. Following analogy instruction novices were also less accurate in the skill-focused condition, but they maintained accuracy under dual-task conditions. Participants in both conditions retained accuracy when ball frequency was slowed, but lost accuracy when ball frequency was speeded, suggesting that not attention, but motor dexterity, was inadequate under high temporal constraints.

Introduction

Cognitive views of movement execution during the early development of a skill hold that it is heavily reliant on the formation, retrieval, and implementation of consciously accessible declarative knowledge in working memory (Anderson, 1993; Fitts & Posner, 1967; Gentile, 1998; Masters & Maxwell, 2004). The attention demands of movement preparation and control during this early *declarative* stage of skill acquisition (Anderson, 1993) are high, but as the learner becomes more proficient, the declarative knowledge that supports movement execution is transformed gradually to become a rich *procedural* representation that is consciously inaccessible and far less attention demanding (i.e., automatic).

Beilock and colleagues (e.g., Beilock, Bertenthal, McCoy, & Carr, 2004; Beilock & Carr, 2001; Beilock, Carr, MacMahon, & Starkes, 2002) and others (e.g., Castaneda & Gray, 2007; Gray, 2004; Jackson, Ashford, & Norsworthy, 2006) have used this 'stages' view of skill acquisition to make specific predictions about the effects of various manipulations of attention on the movement quality of both novice and skilled performers. Novices in the early (declarative) stages of skill acquisition need to consciously monitor and control their movements, whereas experts have progressed, by extensive practice, to a procedural stage in which conscious attention to movement preparation and control is no longer necessary. Beilock, Carr et al. (2002) and Beilock et al. (2004) claimed that manipulations that direct novices' attention away from skill execution have a detrimental effect on movement quality, whereas manipulations that direct novices' attention to the process of movement execution have a beneficial effect on movement quality (e.g., increased accuracy). In experts, the opposite pattern of effects has been claimed (i.e., directing attention away from movement execution to external information should be beneficial to performance and attending to movement execution should be detrimental to performance). There is now an accumulating body of evidence that supports this pattern of effects.

One of the most prevalent manipulations for distracting attention away from movement execution has been to simply ask the performer to perform an attention demanding second task, such as tone counting, word monitoring or random letter generation (Baddeley, 1966), while performing the movement (e.g., Abernethy, 1988; Beilock, et al., 2004; Beilock & Carr, 2001; Beilock, Carr, et al., 2002; Hardy, Mullen, & Jones, 1996; Lewis & Linder, 1997, Masters, 1992; Maxwell, Masters, & Eves, 2000; Mullen, Hardy, & Oldham, 2007). In novice performers, debilitated movement is generally reported, suggesting that there is interference between attention and movement control. In contrast, debilitated movement is not generally reported for skilled performers, suggesting that there is little interference. For example, Beilock et al. (2004) asked novice and expert golfers to perform 20 putts while also monitoring the occurrence of a target tone (which occurred randomly with an average frequency of once every 2 sec). The performance of the novice golfers deteriorated significantly under these conditions, but the performance of experts was unaffected.

Manipulations that direct attention towards rather than away from the control of movement have used evaluation to heighten self-awareness (e.g., Baumeister, 1984; Lewis & Linder, 1997; Liao & Masters, 2002) or have instructed participants to attend to a single component of the skill (e.g., Beilock et al., 2002; Jackson et al., 2006) or to a series of movement cues (e.g., Gucciardi & Dimmock, 2008). In agreement with the predictions of Beilock and colleagues, these skill-focused manipulations have generally disrupted the performance of experts (e.g., Beilock & Carr, 2001; Beilock et al., 2002; Wulf, McNevin, & Shea, 2001), but not novices, even proving beneficial in some cases. For example, Beilock, Carr et al. (2002) instructed both experienced and novice golfers to monitor their golf-putting swing and found that the accuracy of the experienced players was worse than during single-task practice. No differences were present for novices performing under single-task or skill-focused conditions. Similar effects have been shown when baseball batters monitor the swing of their bat (Gray, 2004), field hockey players their hands (Jackson et al., 2006), and soccer players the contact foot when dribbling (Beilock et al., 2002).

The available evidence suggests that novices' execution of motor skills is harmed when attention is distracted away from the task, but not when it is focused on the task, whereas the opposite pattern is evident for expert performers. Beilock et al. (2004) showed the same effects by manipulating the time available for movement execution in a speeded (maximum 3 sec to complete each putt) versus an accuracy condition (take as much time as necessary). Novices were less accurate and experts more accurate in the speeded condition relative to the accuracy condition. In addition, the more time that skilled players took to putt the worse they performed. Beilock et al. suggested that time constraints hamper novices' ability to focus on the task (i.e., restrict skill-focus) denying them the opportunity for conscious monitoring and control that is crucial in the declarative stage. Limited potential for conscious monitoring has, as discussed, little effect on the performance of experts in the procedural stage; conversely, allowing experts ample time to invest attention in skill execution has potential to disrupt performance by perturbing "automated processes that normally run as uninterrupted routines" (Beilock et al., 2004; p. 373; see also Masters & Maxwell, 2008). Episodes in which tennis players miss overhead smashes off towering defensive lobs or soccer players shoot wildly when they seemingly have 'all the time in the world' provide anecdotal support for this argument.

Beilock, Bertenthal, Hoerger, and Carr (2008) recently extended our understanding of the effects of time constraints on performance by differentiating between movement preparation and movement execution. Movement preparation represents the time taken to plan upcoming movements, whereas movement execution refers to the actual movements required to accomplish a skill. In some cases, movement preparation and execution may overlap (e.g., multi-component movements that require adaptation to environmental perturbations). Several studies have demonstrated that movement preparation, relative to execution, is more demanding of attentional resources (e.g., Holroyd, Yeung, Coles, & Cohen, 2005; Lam, Masters, & Maxwell, in press; Lam, Maxwell, & Masters, 2009) suggesting that the majority of cognitive processing occurs in the preparation phase. Based on this reasoning, Beilock et al. (2008) argued that the effects of focusing on skill execution or attending to a dual task should be most prominent in the preparation phase.

To test this assertion, Beilock et al. (2008) contrasted the movement preparation and execution times of novices and experts performing golf putts under conditions that either emphasized accuracy or speeded performance. Novices performed better in the accuracy condition and experts were more accurate in the speeded condition, replicating previous results (Beilock et al., 2004). In addition, reductions in putting time in the speeded condition relative to the accuracy condition were isolated to reductions in the time spent preparing movements (i.e., the period before stroke initiation). Further analysis of the relationship between preparation time and performance outcome revealed that putting accuracy increased with increasing preparation time for novices, but decreased for experts. This pattern of effects supports the notion that novices benefit from online access to declarative knowledge about task performance, whereas experts do not.

The idea that learning progresses from a declarative stage to a procedural stage invokes the possibility that motor behavior of individuals who have attained the latter stage may regress to the earlier stage, under stress, for example (see the progression-regression hypothesis, Fuchs, 1962), or in response to certain manipulations. Evidence for this ‘regression’ hypothesis has been provided by observations of novice-like behavior in experts (e.g., Deschamps, Nourrit, Caillou, & Delignières, 2004), and particularly by the consistent finding that the performance of experts declines when they are required to focus on skill execution (e.g., Beilock, et al., 2002; Gray, 2004). In a novel manipulation of task constraints, Beilock, Wierenga, and Carr (2002) found that experts devoted more attention to their movements when using a “funny putter” that was s-shaped and arbitrarily weighted. Beilock et al. (2008) also found that the funny putter caused experts to become more reliant on preparation time prior to executing their movements, reflecting behavior that was characteristic of novice rather than expert performance.

A corollary of the regression hypothesis is that it may be possible to quicken progression through the declarative stage to the procedural stage (or perhaps by-pass the declarative stage altogether). Masters and Maxwell (2004; see also Masters, 1992) suggested that motor learning need not progress through an early, declarative stage of movement control before becoming automatic (procedural) and argued that expert-like advantages may be augmented by learning in such a way. Accordingly, motor learning techniques have been designed that reduce attention to movement control and encourage the development of procedural knowledge rather than declarative knowledge. For example, Masters (1992) sidetracked the attention of novice golfers over 400 practice trials, with a secondary task that required their constant attention, thus diverting attention away from movement control. The participants reported very low amounts of declarative knowledge about their putting movements, implying that they had learned implicitly. Maxwell, Masters, Kerr, and Weedon (2001) achieved the same effect by reducing the number of errors that learners committed in a golf putting task. They argued that cognitive processes resulting in accretion of declarative knowledge were largely bypassed because there were few errors to correct. This *implicit* form of motor learning has been demonstrated in novice participants over relatively brief periods of task exposure (e.g., 50 to 450 practice trials). Despite limited task exposure, implicit motor learners demonstrate qualities that are normally associated with expertise, such as the ability to perform movement skills without disruption from a secondary task (e.g., Koedijker, Oudejans, & Beek, 2007; Masters, Lo, Maxwell, & Patil, 2008; Lam, Maxwell, & Masters, in press; Maxwell, et al., 2001; Poolton, Masters, & Maxwell, 2006), or from psychological pressure (Hardy, et al., 1996; Koedijker, et al., 2007; Lam, et al., 2009; Liao & Masters, 2001; Masters, 1992), or even physiological fatigue (Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007). However, the effects of skill-focus and time constraints have yet to be examined with regard to implicit motor learning. In the present study we aimed to gain more insight into the effects of attention focus and time constraints on skill learning and performance in novices and experts by means of two complementary experiments. The first used an expert-novice paradigm and the second used instruction.

Experiment 1

In Experiment 1, we sought to replicate and extend the work of Beilock and colleagues on the closed, self-paced skill of golf putting (Beilock et al., 2004; Beilock, Carr, et al., 2002; Beilock & Gonso, 2008; Beilock et al., 2008), to a repetitive, externally-paced skill – the forehand shot in table tennis. Previous studies

(Castenada & Gray, 2007; Gray, 2004) have investigated the effects of different attention manipulations on simulated baseball batting, which is an externally-paced task, but non-repetitive. The repetitive nature of the task allowed us to emulate the speed/accuracy paradigm used by Beilock et al. (2004) in an externally-paced task. Expert and novice table tennis players struck repeated forehand drives at a target, in a simulated rally situation created by a mechanical ball server that projected balls at a fixed trajectory, spin, and velocity. Skilled and unskilled participants performed the table tennis task during both skill-focused/dual-task conditions and during speed/accuracy (speeded/slowed ball frequency) conditions, as well as in a control condition (table tennis task only). The inclusion of this control condition represents an advantage of the current design relative to previous studies, as it allows identification of the causal direction (i.e., beneficial or detrimental) of our manipulations. We expected our novice and expert table tennis players to demonstrate a pattern of effects identical to those observed for novice and expert golf players in previous studies.

Method

Participants

Novice table tennis players (*n* = 15; age *M* = 23.4 years, *SD* = 4.9 years) without table tennis experience were recruited from the Hong Kong student population. Expert table tennis players (*n* = 15; age *M* = 19.1 years, *SD* = 2.6 years) with over 3 years of competitive table tennis experience (*M* = 7.6 years, *SD* = 3.2 years) were recruited from the higher levels of regional competition in Hong Kong. All participants provided informed consent and received a payment of approximately US$10.

Procedure and design

A Donic Robopong 2040 ball server delivered balls (40 mm diameter) with topspin to the forehand side of each participant, at a spin, velocity, and trajectory that was identical for all participants. Participants were informed that their objective was to hit the ball as accurately as possible onto a red target square on the far side of the table. Novice players used a table tennis bat from the Donic Waldner 500 series. Expert players used their own bat, in order to avoid the ‘funny’ putter effect reported by Beilock et al. (2002) and Beilock et al. (2008).

All participants hit 75 practice balls in a familiarization phase, before then hitting 50 balls in each of five conditions: single-task control, skill-focused instruction, dual-task instruction, speeded ball frequency, slowed ball frequency. Condition order was counterbalanced, controlling for possible practice effects. Previous work has neglected to use a single task control condition (e.g., Beilock et al., 2008) or has used practice before the attention manipulations as a baseline measure of single-task performance (e.g., Beilock, Carr et al., 2002; Beilock et al., 2004), leaving practice effects a very real possibility (for exceptions see Jackson et al., 2006; Ford, Hodges, & Williams, 2005).

Single-task control condition. Participants hit 50 forehand return shots. Performance in this condition was considered a measure of baseline accuracy. Balls were served at a frequency of 30/min.

Skill-focused condition. Participants hit 50 forehand return shots and were required to monitor their movements during each shot, in order to say “angle” at ball contact (consistent with Beilock et al., 2004). Bat angle is important for control of ball spin, direction, and trajectory. Balls were served at a frequency of 30/min.

Dual-task condition. Participants hit 50 balls while simultaneously listening to a series of 6 one-syllable names of animals, which occurred randomly in equal numbers at 2-sec intervals (adapted from Beilock, Wierenga, & Carr, 2002). Participants were instructed to repeat the target word each time that they heard it. Balls were served at a frequency of 30/min.

Slowed condition. In the slowed condition, participants hit 50 balls that were served at a frequency of 20/min, rather than 30/min. Participants were informed that the balls would be served at the same velocity, direction, and trajectory, but that more time would be available between shots. In other words, participants had more time to prepare their movements. This condition replicated Beilock et al.’s (2004, 2008) accuracy condition.

Speeded condition. In the speeded condition, participants hit 50 balls that were served at a frequency of 40/min, rather than 30/min. Participants were informed that the balls would be served at the same velocity, direction, and trajectory, but that less time would be available between shots. This condition was designed to reduce the amount of time participants had available to prepare their movements (consistent with Beilock et al., 2004, 2008).

The position at which each ball landed relative to the target square was captured by a digital video camera (Panasonic NV-G8280). A measurement grid consisting of 45mm x 45mm squares was marked around a target square (also 45mm × 45mm), which was positioned on the center line of the table, 472.5mm from the far end of the table. Balls that missed the table, hit the net, or landed further than 472.5mm (10.5 squares) from the center of the target received a default error score of 472.5mm - the shortest distance by which a ball could miss the target square without landing on the table. Mean absolute distances by which the ball missed the target are reported in Table 1. For comparability with the work of Beilock and colleagues (Beilock et al., 2004, 2008; Beilock, Carr et al., 2002), comparisons were made with two separate ANOVAs, one comparing skill-focus and dual-task conditions and one comparing slowed and speeded conditions[*]. Subsequently, extending the work of Beilock and colleagues, paired *t*-tests were performed to examine whether performance in the experimental conditions differed from performance in the control condition (tests were one-tailed due to the directional nature of our predictions).

Results

Skill-focused versus dual-task performance

Performance in the experimental conditions relative to the control condition is presented in Figure 4.1 (skill-focus, dual-task) and Figure 4.2 (speeded, slowed). In all figures, positive means indicate performance that was less accurate than single task control performance and negative means indicate performance that was more accurate than single task control performance.

An Expertise (novice, expert) × Condition (skill-focused, dual-task) analysis of variance (ANOVA) revealed a significant main effect for expertise, $F(1, 28) = 87.14$, $p < .001$, $\eta_p^2 = .76$, without the presence of a main effect for condition, $F(1, 28) = .26$, $p = .62$, $\eta_p^2 < .01$. An Expertise × Condition interaction was evident, $F(1, 28) = 4.72$, $p < .05$, $\eta_p^2 = .14$. Experts were more accurate in the dual-task condition than in the skill-focused condition, $t(14) = 3.39$, $p < .01$, $d = .40$. Although novices showed the opposite pattern of performance, the differences were not significant, $t(14) = 0.91$, $p = .19$, $d = .15$ (see Figure 4.1).

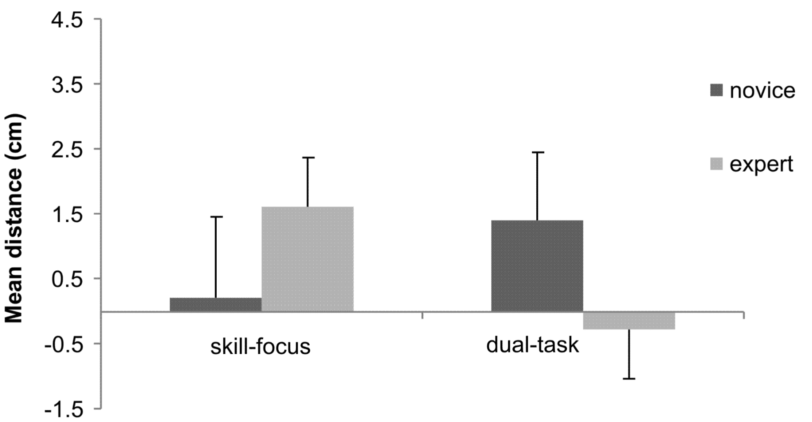

Figure 4.1. Average distance (cm) to the target relative to the control condition for novice and expert table tennis players in the skill-focused and the dual-task conditions in Experiment 1. Error bars indicate standard errors.

Paired *t*-tests were used to compare performance in the skill-focused and the dual-task conditions with performance in the single-task control condition (see

[*] Comparison of conditions that were predicted to have the same effect (i.e., skill-focus and slowed conditions; dual-task and speeded conditions) revealed no statistical differences

Beilock et al., 2004). For the experts, performance was less accurate in the skill-focused condition than in the single-task control condition, $t(14) = 2.34$, $p < .025$, $d = .42$, but not different in the dual-task condition compared to the single-task control condition ($p = .36$). For the novices, performance in neither the dual-task condition ($p = .11$) nor the skill-focused condition ($p = .44$) differed from performance in the single-task control condition.

Secondary task performance

On no occasion did a participant fail to say "angle" at ball contact in the skill-focused condition or fail to identify the target word in the dual-task condition.

Slowed versus speeded performance

An Expertise (novice, expert) × Condition (slowed, speeded) ANOVA revealed a significant main effect for expertise, $F(1, 28) = 104.01$, $p < .001$, $\eta_p^2 = .79$, without a significant main effect for condition, $F(1, 28) = .69$, $p = .41$, $\eta_p^2 = .02$. An Expertise × Condition interaction was evident, $F(1, 28) = 9.37$, $p < .01$, $\eta_p^2 = .25$. As can be seen in Figure 4.2, novices were more accurate in the slowed condition than in the speeded condition, $t(14) = 2.38$, $p < .025$, $d = .33$, and experts were less accurate in the slowed compared to the speeded condition, $t(14) = 1.95$, $p = .035$, $d = .25$ (see Figure 4.2).

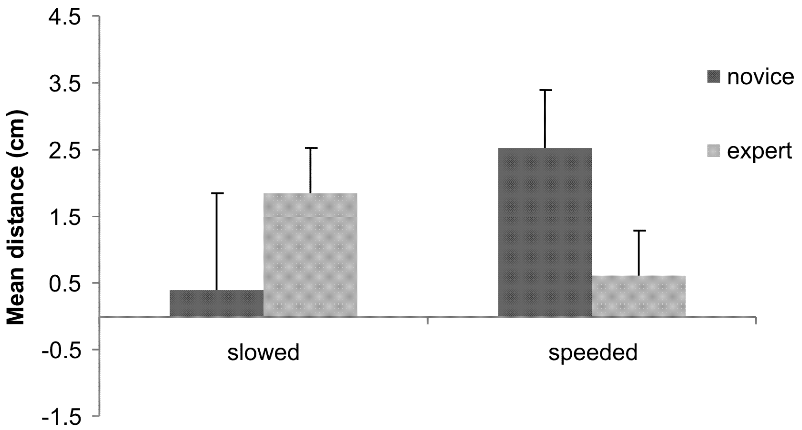

Figure 4.2. Average distance (cm) to the target relative to the control condition for novice and expert table tennis players in the slowed and the speeded conditions in Experiment 1. Error bars indicate standard errors.

Paired *t*-tests (one-way) were used to compare performance in the speeded and the slowed conditions with performance in the single-task control condition. For the novices, performance was less accurate in the speeded condition than in the single-task control condition, $t(14) = 2.96$, $p < .025$, $d = .36$, but not different in the slowed condition compared to the single-task control condition ($p = .39$). In contrast, for experts, performance was less accurate in the slowed condition than the control condition, $t(14) = 2.91$, $p < .025$, $d = .46$, but not different in the speeded condition compared to the control condition ($p = .16$).

Discussion

Experiment 1 was conducted to replicate and extend a series of studies that examine direction of attention in novice and expert performers (Beilock, Carr et al., 2002; Beilock et al., 2004, 2008) by incorporating a control group and using a repetitive, externally-paced motor task, rather than a single, discrete task, such as golf putting or baseball batting. Experts showed poorer accuracy when a skill-focused instruction directed their attention to control of their movements or when the frequency of balls was slowed to allow more time to hit the ball. This pattern of results replicates recent findings (Beilock et al., 2002; 2004; 2008; Castaneda & Gray, 2007) and is consistent with existing theories of conscious processing (e.g., theory of reinvestment, Masters, 1992; Masters, Polman, & Hammond, 1993; Masters & Maxwell, 2008; explicit monitoring theory, Beilock & Carr, 2001; constrained action hypothesis, Wulf et al., 2001), all of which suggest that the performance of relatively automated movements can be disrupted in situations in which a performer is directed to focus attention on skill execution, or in which the time constraints are relaxed so that attention can easily be directed to movement.

The performance of experts has on occasion been shown to benefit from dual-task conditions (e.g., Allard & Burnett, 1985; Jackson et al., 2006). Jackson et al. argued that for experts, diversion of attention to a second task potentially “burns off” disruptive residual conscious processing of movements that can occur in single task conditions. The absence of performance benefits in both dual task and speeded conditions suggests that the experts in the current experiment had little interference from residual conscious processing during single-task performance, indicating that their control structures may have been more integrated or more automated than in other studies. For example, although Beilock et al.’s (2004; 2008) golfers had a fair amount of experience and demonstrated a relatively high level of skill they were not experts by current standards. In addition, neither study utilized a single task control condition, making comparisons difficult.

The performance of novices typically does not benefit from dual-task demands. Processing resources that are normally available for movement control must be deployed to carry out the secondary task (Abernethy, 1988; Beilock & Carr, 2001; Lewis & Linder, 1997; Masters, 1992). Novices in the current study were unaffected by dual task conditions, relative to performance in the single task control condition. It is possible that the word monitoring task demanded too few attention resources to be disruptive (or perhaps allowed novices to switch their attention between tasks). It may be necessary to increase the demands of the word monitoring task to be sure that attention can not be deployed for movement control (also see Jackson et al., 2006).

Novices were less accurate in the speeded condition (when they had less time to prepare to hit the ball), relative to performance in the slowed and single task conditions in which their performances did not differ. Previous research has shown that novices reduce their preparation time when faced with time constraints (Beilock et al., 2008), which prevents them from applying declarative knowledge to or assuming conscious control of their movements. The externally imposed time constraints in the current experiment seem to have had similar effects.

Experiment 2

In Experiment 2 we compared novices who were instructed how to hit balls via an approach that explicitly encouraged attention to real-time execution with novices who were instructed via an implicit approach, which de-emphasized attention to real-time execution. For the explicit approach, we presented novices with a script of five traditional training instructions that detailed how to hit a topspin forehand. Previous research has shown that novices instructed in this manner have great difficulty maintaining performance under dual task and time-limited conditions (e.g., Masters, Poolton, Maxwell, & Raab, 2008; Poolton et al., 2006), because they are impeded from applying their declarative knowledge to the performance of the motor task. Skill-focused instructions should have little effect on the performance of these individuals because, according to conscious processing theories, this is their normal modus operandi. The provision of ample time to prepare movements should also prove advantageous to novices instructed in this manner.

For the implicit approach, we presented novices with a single motor analogy that has been previously validated as an implicit motor learning method for the table tennis forehand (Koedijker, et al., 2007; Liao & Masters, 2001; Poolton, et al., 2007). Masters (2000) considered motor analogies to be ‘biomechanical metaphors’ that repackage the individual step-by-step components of a motor skill as a representation of the movement that can be conveyed to the learner in a single instruction. Rather like a ‘rule of thumb’ or a ‘fast and frugal’ heuristic (Gigerenzer & Goldstein, 1996), the representation bypasses slow and unwieldy step-by-step declarative processes during movement preparation and execution. As a consequence, novices who learn by analogy should show characteristics of expertise that include more accurate performance in dual-task conditions, relative to skill-focused conditions, and under high temporal demands imposed by speeded ball frequency, relative to low temporal demands imposed by slowed ball frequency.

Methods

Participants

Novice table tennis players with no table tennis experience were recruited from the local student population. After providing informed consent they were randomly divided into an explicitly instructed group (Explicit Group, n = 15, age M = 20.5 years, SD = 0.9 years) or an analogy instructed group (Analogy Group, n = 14, age M = 21.9 years, SD = 3.7 years). All participants received a payment of approximately US$10.

Procedure and Design

The design and set-up of the experiment were identical to Experiment 1 apart from a few minor changes to the protocol. First, prior to the familiarization trials, participants received instructions about how to hit the table tennis ball. The Explicit Group received a list of 5 step-by-step rules (adapted from Hodges, 1993) that explained how to move to hit the ball correctly. The rules were (1) keep your feet a little wider than shoulder wiDTTh apart, (2) position your feet behind the table with the right foot furthest from the table, (3) move the bat backwards and down, (4) move your body weight to the front leg, and (5) move your playing arm forwards and upwards. The Analogy Group received a single analogical instruction: “move the bat as though it is travelling up the side of a mountain” (cf. Poolton et al., 2007). This verbal instruction was exemplified by an illustration of a bat moving up the side of a mountain. Second, the demands of the word-monitoring task that was used in the dual-task condition were increased to counter the possibility that dual task interference was absent for novices in Experiment 1 because the word-monitoring task was too easy. Participants listened to the same series of six one-syllable names of animals that was used in Experiment 1, but rather than repeat the target word each time that they heard it, they instead repeated the name of the animal that preceded the target word.

Finally, all participants completed verbal protocols at the end of the experiment, in which they described, in as much detail as possible, the movements, methods, and techniques that they remembered using to hit the ball. Previous work has shown that the amount of movement knowledge that is reported is related to performance degradation in attention demanding conditions (e.g., Koedijker et al., 2007; Liao & Masters, 2001).

Results

Similar to Experiment 1, the position at which each ball landed relative to the target square was used as a dependent variable. Mean absolute distances are reported in Table 4.2. Similar to the figures in Experiment 1, Figures 4.3 and 4.4 illustrate performance of the two experimental groups in the different conditions relative to accuracy in the single-task control condition. Again, positive means indicate performance that was less accurate than single task control and vice versa.

Skill-focused versus dual-task performance

An Instruction (explicit, analogy) × Condition (skill-focused, dual-task) ANOVA revealed that main effects were not present for instruction, $F(1, 27) = .68$, $p = .42$, $\eta_p^2 = .03$, or for condition, $F(1, 27) = 2.10$, $p = .16$, $\eta_p^2 = .07$. A significant Instruction × Condition interaction was evident, $F(1, 27) = 4.81$, $p < .05$, $\eta_p^2 = .15$. Participants in the Analogy Group were more accurate in the dual-task condition than in the skill-focused condition, $t(13) = 2.48$, $p < .05$, $d = .83$, whereas participants in the Explicit Group showed no difference in accuracy in the skill-focused and dual-task conditions $t(14) = 0.54$, $p = .60$, $d = .18$ (see Figure 4.3).

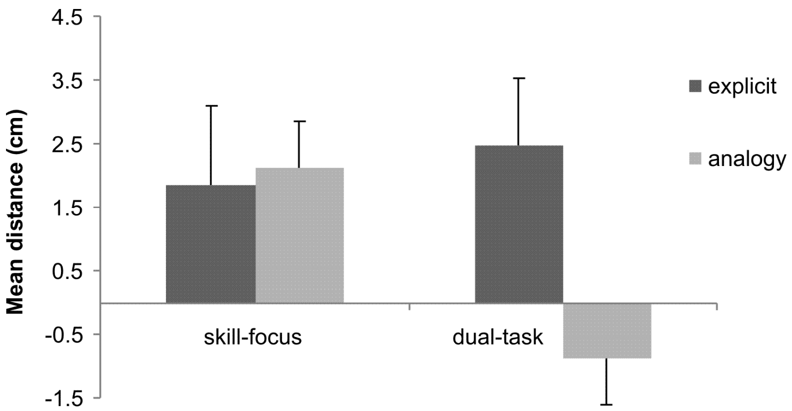

Figure 4.3. Average distance (cm) to the target relative to the control condition for the Explicit Group and the Analogy Group in the skill-focused and the dual-task conditions in Experiment 2. Error bars indicate standard errors.

Paired *t*-tests were used to compare performance in the skill-focused and the dual-task conditions with performance in the single-task control condition. For both the Explicit Group and the Analogy Group, respectively, performance was less accurate in the skill-focused condition than in the single-task control condition, $t(14) = 2.72$, $p < .05$, $d = .76$ and $t(13) = 2.90$, $p < .05$, $d = .48$. Participants in the Explicit Group were also less accurate in the dual-task condition than in the single-task control condition, $t(14) = 2.30$, $p < .05$, $d = .62$, but no difference was evident for the Analogy Group ($p = .45$). Providing a single analogical instruction rather than a set of step-by-step instructions appears to have an immediate effect on deployment of the attention of novices during movement.

Secondary task performance.

Responses in the word monitoring task were 89% correct, with participants from both groups showing equal proficiency (p = .19). On no occasion did a participant fail to say “angle” at ball contact during the skill-focused condition.

Slowed versus speeded performance

An Instruction (explicit, analogy) × Condition (slowed, speeded) ANOVA revealed a main effect of condition, $F(1, 27) = 13.89$, $p < .01$, $\eta_p^2 = .54$, but not of instruction, $F(1, 27) = .25$, $p = .62$, $\eta_p^2 < .01$. The Instruction × Condition interaction failed to reach significance, $F(1, 27) = 2.32$, $p = .14$, $\eta_p^2 = .08$. Figure 4.4 shows that performance in the speeded condition was less accurate than performance in the slowed condition.

Paired t-tests were again used to compare performance in the speeded and slowed conditions with performance in the single-task control condition. For both the Explicit and the Analogy Group, accuracy was worse in the speeded condition than in the control condition, $t(14) = 3.18$, $p < .01$, d =.85 and $t(13) = 2.52$, $p < .05$, d =.88, respectively. No differences were found for performance in the slowed condition compared to the control condition (p = .67 & p = .24, respectively). It appears that the robust performance shown by the Analogy Group in the dual-task condition was not evident in the speeded condition, suggesting that advantages apparent for experts in these conditions may not be due to a shared underlying mechanism.

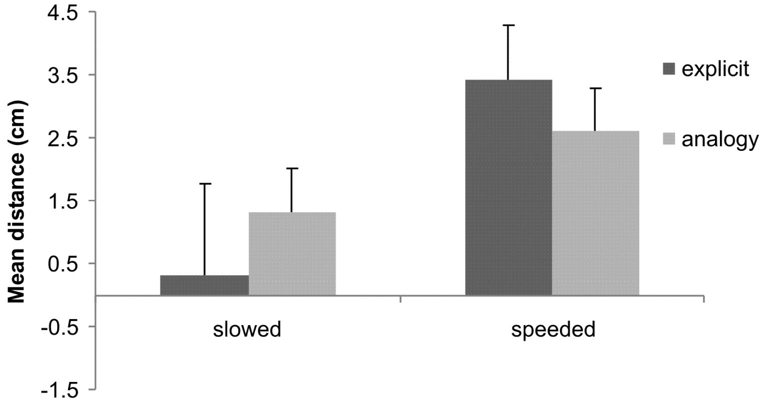

Figure 4.4. Average distance (cm) to the target relative to the control condition for the Explicit Group and the Analogy Group in the slowed and the speeded conditions in Experiment 2. Error bars indicate standard errors.

Verbal protocols

Four independent raters totaled the movement knowledge reported by each participant. The raters were blind to the participant’s treatment group. The totals were then compared and discrepancies discussed until a consensus was reached. An independent-samples *t*-test was used to compare the two groups. As expected, significantly more movement knowledge, $t(27) = 3.33$, $p < .005$, $d = 1.23$, was reported by participants in the Explicit Group ($M = 4.73$ rules, $SD = 1.22$ rules) than in the Analogy Group ($M = 3.14$ rules, $SD = 1.35$ rules).

Discussion

Presentation of an analogy instruction to novices with relatively "unintegrated" movement control structures (Beilock et al., 2004) appears to have reduced the tendency (or need) to direct attention towards step-by-step execution, as implied by performance in the Analogy Group that was unaffected by dual-task conditions (despite the increased difficulty of the word monitoring task). Taken together with the limited number of rules reported by the Analogy Group compared to the Explicit Group, this suggests that the analogy bypassed the declarative stage of learning that is typically associated with online preparation, control, and correction of movement (Anderson, 1993). However, speeded conditions were disruptive to the performance of participants in the Analogy Group. The performance of these participants, unlike the experts in Experiment 1, may have been disrupted at a neuromuscular level, rather than at a higher information processing level. It is likely that in the early stages of learning, with so little practice, the neuromuscular system of the novice analogy learners lacked the flexibility to adapt to the temporal constraints imposed by the higher ball frequency. With increased task experience, as is the case for experts, the participants in Experiment 2 are likely to have become more adept at finding adequate motor solutions in demanding conditions (Beek, 2000), such as high temporal constraints.

General Discussion

These experiments aimed to replicate and extend the findings of Beilock and Carr et al. (2002) and Beilock et al. (2004, 2008) by studying attentional processes under skill-focus, dual-task, speeded and slowed conditions in the context of an externally-paced, repetitive task rather than the often used self-paced task of golf-putting. The inclusion of a single-task control condition allowed for more specific inferences about the direction of the effects of the different manipulations. Furthermore, we examined how an analogical instruction mediated performance under the experimental conditions of interest.

Our findings generally are in concordance with previous research (e.g., Beilock et al., 2002, 2004, 2008). Manipulations that diverted attention away from real-time skill execution or narrowed the temporal window through which attention could be directed to execution, had no impact on the performance of experts, but were harmful to the performance of novices, with the exception of the novices in Experiment 2 who were provided with an analogy instruction seemed to place few demands on working memory. The analogy may have allowed novices to somehow by-pass the need for explicit control of real-time execution early in learning.

Attention in novice and expert performance: Conscious control and reinvestment
Manipulations which steered attention to real-time skill execution in Experiment 1 had no effect on performance of novices, but were harmful for experts. Instructions that direct attention to specific components of a movement have been claimed to enhance the performance of novices (e.g., Beilock, Carr et al., 2002; Castaneda & Gray, 2007; Gray, 2004, Perkins-Ceccato et al., 2003), because movement execution in the early stages of learning is more responsive to conscious control (Beilock et al., 2004). Beilock et al. (2008) contrasted the movement preparation and execution times of novices and experts in conditions that emphasized accuracy or speeded performance. Novices performed better in the accuracy condition, but experts were more accurate in the speeded condition (see also Beilock et al., 2004). In addition, quicker putting times in the speeded condition, relative to the accuracy condition, were isolated to reductions in the time spent preparing movements (e.g., the period before stroke initiation). The accuracy of novices improved when preparation time was longer, where the accuracy of experts deteriorated. This pattern of effects supports the notion that novices benefit from online access to declarative knowledge about movement execution, whereas experts do not. It would be of interest to examine accuracy for preparation times in participants instructed by analogy in Experiment 2. Presumably, they would show a pattern of behavior similar to experts if their attention control structures indeed are less akin to declarative than procedural control of movement.

The problem with the argument constructed by Beilock and her colleagues is that novice performance is actually characterized by reliance on attention resources to guide action in a step-by-step fashion (Anderson, 1993; Fitts & Posner, 1967) – attending to movement execution is just what novices do. The potential benefits of skill-focused instructions may simply be that they do not interfere with the preferred (current) attention focus of the novice performer, implying that performance, at best, is unlikely to be hampered by skill-focused conditions. Beneficial effects may therefore occur because skill-focused instructions direct attention to the right cues. For example, an instruction to “keep the club head straight while you hit the ball” (Beilock et al., 2004) provides movement related information that can enhance accuracy irrespective of directing attention towards skill-execution.

For the novices in Experiment 2, however, attention to movement execution in the skill-focused condition was actually harmful to performance, regardless of whether the novices were instructed explicitly or by analogy. It is possible that saying "angle" at ball contact in the explicit group interfered with the capability to process and use the rules that were provided about how to hit the table tennis forehand, resulting in disrupted performance. Alternatively, the combination of processing rules and concentrating on saying 'angle' at the correct moment caused participants to neglect (or overlook) essential components of performance, such as critical movement parameters or crucial ball-flight information. These arguments are less convincing for the analogy learners, who received only a single declarative rule. An alternative explanation is that the analogy instruction advanced the performance of the novices more rapidly towards expertise (i.e., more integrated control structures), and thus the skill-focused instruction was harmful to performance because it drew attention to specific components of performance better left to run automatically (e.g., Beilock, Carr et al., 2002).

Beilock et al. (2004, 2008) demonstrated that instructions to perform accurately in as little time as possible caused better performance than instructions to perform accurately, taking as much time as necessary. The findings of Experiment 1 suggest that experts do not become more accurate, at least in a task such as table tennis, when the temporal window for movement execution is narrowed. However, Beilock and colleagues (2004, 2008) allowed participants to choose their own time frame within the temporal constraints of the studies in question (e.g., 3 sec). The participants may have been able to select the shortest time frame in which performance remained optimal. In the present work, the speeded ball frequency condition may have imposed time constraints that did not allow such tolerances. Furthermore, instructions to "take as much time as you need" may have caused participants to take more time than was optimal for performance (Beilock, Afremow, Rabe, & Carr, 2001; De la Pena, Murray, & Janelle, 2008).

Attention, instruction and task specificity: Self-paced vs. externally-paced tasks

The fairly minor differences that we find may also be a consequence of extending the previous work to a repetitive, externally-paced task. Self-paced and externally-paced tasks have been shown to utilize neurophysiologically distinguishable control circuits (Gazzaniga, 2004), with self-paced tasks eliciting stronger neural activation than externally triggered tasks (Gerloff, Richard, Hadley, Schulman, Honda, & Hallett, 1998; Wessel, Zeffiro, Toro, & Hallett, 1997). It may be that in self-paced tasks, more so than in externally-paced tasks, conditions that narrow the temporal window for movement execution are more likely to evoke an automatic mode of control that weakens the impact of residual conscious processing. This argument is similar to the suggestion that expert performance potentially can benefit from dual-tasking because diverting attention to the second task "burns off" disruptive residual conscious processing of movement (Jackson et al., 2006). Furthermore, the absence of performance benefits for the experts under dual-task conditions (Experiment 1) implies that they may have been more expert (relatively) than the skilled players used by Beilock et al. (2004, 2008), who benefited from dual-task conditions. Compared to skilled performers, experts may have less residual conscious processing and thus benefit less from a narrow temporal window for movement execution. In seeking to interpret the effects of varied movement preparation time on performance we recognize that further research must disentangle effects of task-specificity, level of expertise, and the nature of the instructions that are provided under different temporal constraints.

Effects of an analogical instruction on skill acquisition

The effects of instruction by analogy on attention demands during performance have been relatively consistent across a number of studies (Koedijker et al., 2007; Lam et al., 2009; Lam et al, in press; Law, Masters, Bray, Bardswell, & Eves, 2003; Liao & Masters, 2001; Poolton, et al., 2007; for an exception, see Koedijker, Oudejans, & Beek, 2008). These studies have demonstrated that novice performers, over varying amounts of practice, tend to show little or no disruption of performance under dual-task conditions. The present work adds to this literature by showing that even with only a very limited number of practice trials (n = 75, Experiment 2), novice participants instructed by analogy were unaffected by dual-task conditions. The analogy instruction appears to guide the learner in such a way that the testing of movement related hypotheses, via working memory involvement, is much reduced (impoverished declarative knowledge of task execution has been taken as evidence of this). As a consequence, the control structures that preside over the performance of the novice might be more procedural than declarative.

Despite appearing to have more expert-like attention control structures, the participants instructed by analogy were unable to retain performance accuracy under high temporal demands, imposed by speeded ball frequency. Presumably, further trials (repetition) would be accompanied by motor behavior more flexible in the face of such constraints. It would be interesting to train novices under high temporal constraints, as it is unlikely that working memory resources can be utilized to test movement related hypotheses if too little time is available to process error information. Consequently, this might result in an effect similar to analogy learning, with the declarative phase of learning less prominent. Of course, novices learning under high temporal constraints might also commit a high number of errors, which has been shown to cause a highly declarative mode of learning (Maxwell et al., 2001).

To some extent this explanation fits Bernstein’s (1996) notion that attaining automaticity is only one of the first steps in achieving expertise, followed by the parallel processes of standardization and stabilization. These processes can be considered as the fine-tuning of skill towards consistent and flexible behavior. Standardization of automatic movement involves the acquisition of extraordinarily accurate repeatability of movement execution and is prominent in the improvement of skills such as cigar making or basketball free throw shooting even after millions of repetitions (Crossman, 1959; Kottke, 1980). Stabilization of movement automaticity is the process of acquiring resistance of performance to disruptive influences, such as increased temporal demands. Although the analogy instruction in the present study appeared to circumvent the declarative stage of learning, the disrupted performance displayed by the analogy learners in the speeded condition suggests that their movements had not stabilized enough to cope with the disruptive influence of increased temporal demands. Implicitly learned skills have been shown to be resistant to the disruptive influence of physiological fatigue, however, implying that implicit learning techniques may, to some extent, facilitate the stabilization of movement automaticity (Masters et al., 2008; Poolton et al., 2007).

Theoretical accounts of movement sequence learning can also provide an explanation of the pattern of performance shown by analogy instructed participants. These accounts suggest that two hierarchically organized learning systems develop independently and at different rates (e.g., Keele, Jennings, Jones, Caulton, & Cohen, 1995). One system specifies the sequence order (movement structure) and is represented at an abstract, explicit level, whereas the other system represents the management of the actual forces involved in movement production (effector dynamics; Hikosaka, et al., 1999; Park & Shea, 2002; Rosenbaum, 1990; Wilde & Shea, 2006). The cognitive representation of the sequence structure is thought to develop at a quicker rate than the effector-dependent movement dynamics. For analogy learners the sequence structure might be established very early in learning as there is only one rule to integrate into movement execution. With the establishment of the movement structure the first signs of automaticity become visible (i.e., stable performance under secondary task loading), but the motor system needs more time and practice to stabilize and standardize the movement dynamics. Evidently, studying the effects of analogy learning over longer periods of learning (well into the phases of stabilization and standardization) is a direction that future research should take.

Overall, our findings seem to fit fairly well with the growing body of literature that examines attention control during motor performance. Expert motor performance can be disrupted by “re-instantiation of explicit skill-monitoring and control mechanisms” (Beilock et al., 2004, p. 379), a phenomenon described by Masters (1992) as ‘reinvestment’ (see for a recent review, Masters & Maxwell, 2008). Conversely, explicit skill-monitoring may aid performance of novices who rely heavily on declarative components of performance. Teaching aids, such as analogy instructions, which prompt novices to rely less heavily on declarative components of performance, may promote expert-like attention control structures (e.g., which allow robust performance under dual-task conditions) without necessarily leading to expert-like motor execution (e.g., as shown by disrupted performance under high temporal demands). It would seem that the objective should not be to ‘just do it’, but rather to “think – and not make thoughts your aim….” (Kipling, 1910).

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