Analogy Learning and the Performance of Motor Skills Under Pressure

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The efficacy of analogical instruction, relative to explicit instruction, for the acquisition of a complex motor skill and subsequent performance under pressure was investigated using a modified (seated) basketball shooting task. Differences in attentional resource allocation associated with analogy and explicit learning were also examined using probe reaction times (PRT). Access to task-relevant explicit (declarative) knowledge was assessed. The analogy and explicit learning groups performed equally well during learning and delayed retention tests. The explicit group experienced a drop in performance during a pressured transfer test, relative to their performance during a preceding retention test. However, the analogy group’s performance was unaffected by the pressure manipulation. Results from PRTs suggested that both groups allocated equal amounts of attentional resources to the task throughout learning and test trials. Analogy learners had significantly less access to rules about the mechanics of their movements, relative to explicit learners. The results are interpreted in the context of Eysenck and Calvo’s (1992) processing efficiency theory and Masters’s (1992) theory of reinvestment.

Keywords: anxiety, attention, basketball, explicit, implicit

It is not uncommon to see deterioration in the performance of a variety of motor tasks when a performer is under pressure (e.g., basketball shooting, Hardy & Parfitt, 1991; Whitehead, Butz, Kozar, & Vaughn, 1996; golf putting, Hardy, Mullen, & Jones, 1996; Masters, 1992; or playing piano, Wan & Huon, 2005). It is unsurprising, therefore, that considerable effort has been invested in the search for effective methods of dealing with pressure or in developing coaching techniques that encourage the development of motor skills that are less susceptible to the effects of pressure. We report a study that takes the latter approach; specifically, we examined the effects of different types of coaching instruction on the acquisition of a complex motor skill and subsequent performance under pressure.
The Pressure-Performance Relationship

Research examining the effects of pressure on skilled performance has a long history (e.g., Baumeister, 1984; Bliss, 1895; Maxwell, Masters, & Poolton, 2006). Performance pressure is associated with increased cognitive and somatic anxiety (Jones & Hardy, 1989), self-consciousness (Liao & Masters, 2002), and worry (Baumeister, 1984). Crucially, performance pressure is often accompanied by deterioration in the performer’s ability to execute movements correctly, a phenomenon that has been referred to as “choking under pressure” (e.g., Baumeister, 1984; Baumeister & Showers, 1986; Beilock & Carr, 2001). Baumeister (1984), for example, demonstrated that pressure induced by being observed caused performance decrements in experienced video game players.

Several theories offer an explanation for performance deterioration under pressure. Eysenck and Calvo (1992), for example, proposed a processing efficiency theory (PET) of skill breakdown under pressure. They argued that task performance worry or anxiety consumes working memory resources and this may directly affect performance. However, they noted that anxiety does not always lead to a breakdown in performance. They argued that the performer can compensate for increased worry by devoting more resources to maintain task performance (i.e., decreased processing efficiency) such that performance breakdown only occurs if these resources are still insufficient (Wilson, 2008). Evidence for the validity of the PET for motor performance has been provided by several studies (for a recent review, see Wilson, 2008), although the prediction that efficiency is dependent on quantity of information processed in working memory has not always been supported (Williams, Vickers, & Rodrigues, 2002). Eysenck and colleagues (Eysenck, Derakshan, Santos, & Calvo, 2007) later expanded PET into the attentional control theory (ACT) to incorporate specific aspects of working memory function, namely, inhibition of irrelevant information and shifting attention from one source of information to another; however, evidence for the validity of ACT is scarce within the sporting domain (Wilson, 2008).

Recently, consciously processing explicit knowledge of movement components during task execution has been (re)implicated as a possible mechanism for skill breakdown (e.g., Beilock & Carr, 2001; Masters, 1992). Masters (1992) noted that explicit knowledge of what to do when executing a movement is typically generated during the early stages of learning as the learner tries to work out the most effective movement patterns. With practice, this explicit knowledge becomes less influential as automatic movement control processes develop (e.g., Fitts & Posner, 1967; Shiffrin & Schneider, 1977; Whiting, 1984). Masters (1992) argued that one of the reasons for skill breakdown under pressure is that explicit knowledge is “reinvested” in the movement, disrupting automatic movement control (for a recent review of reinvestment theory, see Masters & Maxwell, 2008). Hardy et al. (1996) described this as the conscious processing hypothesis (CPH). In other words, instead of allowing automatic execution, the performer consciously tries to control movements in a step-by-step fashion using explicit knowledge of what should be done. Conscious control also places high demands on working memory resources, which may also lead to performance breakdown, consistent with PET. Thus, the CPH suggests that performance breakdown can be viewed as a consequence of the amount of processing (quantity) and/or type of information processed (quality).
Intervention Strategies to Prevent Choking Under Pressure

The majority of interventions have focused on the performer’s ability to reduce anxiety (e.g., by relaxation) or to ameliorate the effects of increased anxiety (e.g., through desensitization to stressors; Beilock & Carr, 2001; Lewis & Linder, 1997). Few researchers have considered the possibility of applying interventions during the skill acquisition stage. Based on the theory of reinvestment, Masters (1992) argued that one way of preventing skill breakdown under pressure might be to restrict the development of explicit knowledge or to learn implicitly. Implicit learning has been broadly defined as the acquisition of skills in the absence of explicit knowledge of the underlying information that guides performance (see Reber, 1993). Masters further argued that working memory (see Baddeley, 1997) is critically involved in the generation, maintenance, and manipulation of explicit movement knowledge. Thus, the development of explicit knowledge should be prevented or severely restricted by engaging working memory in tasks unrelated to the primary motor skill.

To prevent working memory from generating task-relevant explicit knowledge, Masters (1992) had participants in an implicit motor learning condition practice a golf putting task while concurrently performing a secondary task (random letter generation; Baddeley, 1966). In a second explicit learning condition verbal (coaching) instructions were presented. Performance in both conditions increased during 400 learning trials, but participants in the implicit motor learning condition were unable to describe the methods that they had used to perform the putting task. Crucially, when placed under pressure (monetary incentive and expert evaluation) participants in the implicit condition continued to improve, whereas participants in the explicit motor learning condition did not.

Masters’s (1992) basic findings have since been replicated and extended several times (e.g., Hardy et al., 1996; Mullen, Hardy, & Oldham, 2007); however, the secondary task protocol has been criticized because of difficulties in applying it to typical learning scenarios (e.g., Beek, 2000) and the tendency for secondary tasks to suppress performance (MacMahon & Masters, 2002; Maxwell, Masters, & Eves, 2000). Consequently, alternative implicit motor learning paradigms have been developed that involve error reduction in the very early stages of learning (Maxwell, Masters, Kerr, & Weedon, 2001), reduced feedback (Maxwell, Masters, & Eves, 2003), or provision of feedback at an unconscious level (i.e., subliminal feedback; Masters, Maxwell, & Eves, 2001). All of these paradigms promote motor learning with only marginal explicit knowledge of task mechanics. Unfortunately, each of these techniques has drawbacks that limit their application to athletic training. The subliminal feedback paradigm, for example, requires presentation of knowledge of results using a three-field tachistoscope.

To overcome the practical problems associated with other implicit motor learning techniques, Masters (2000) suggested the use of analogy. Movement analogies are intended to reduce multiple task-relevant “rules” into a single “all encompassing biomechanical metaphor” (Masters, 2000, p. 538). Liao and Masters (2001) tested this suggestion by asking participants to focus on a single analogical rule when learning a table tennis topspin forehand shot. They predicted that this would result in implicit motor learning. In their first study, novices learned
for six blocks of 50 trials using either 12 explicit coaching instructions about how to perform the topspin forehand shot or a right-angled triangle analogy, which required the bat to travel along the hypotenuse of an imagined triangle during the hitting movement. Liao and Masters found that the performance of the two groups was identical following learning; however, the analogy group reported significantly fewer rules than the explicit group, suggesting that the analogy had effectively restricted conscious explicit processing (and storage) of task-relevant information. In addition, when asked to perform a secondary task concurrently with the primary motor task, the performance of the explicit group deteriorated, whereas the performance of the analogy group was unaffected. This result suggested that participants in the analogy group had sufficient free attentional resources to perform the secondary task whereas the explicit group did not.

In a second experiment, Liao and Masters (2001) provided evidence that analogy learners were also resistant to the negative effects of pressure, relative to explicit learners. Again, learners were provided with either a single analogy or multiple explicit rules before learning a top-spun forehand table tennis shot. Following learning, participants were informed that their performance to that point had been extremely poor and much worse than other participants, and they were criticized for their lack of effort. Berated in this fashion, participants (unsurprisingly) reported significant increases in cognitive anxiety. The performance of the explicit group declined in these anxiety-provoking conditions whereas the analogy group’s performance increased significantly.

Similar results were produced by Law, Masters, Bray, Eves, and Bardswell, (2003), also using the right angle triangle analogy. Analogy and explicit learners were placed under stress in the presence of neutral, supportive, and adversarial audiences. Analogy learners’ performances were robust to the effects of stress in all three conditions, whereas explicit learners’ performances were adversely affected in the presence of the supportive audience. These results were interpreted as support for the notion that analogy learners have limited explicit knowledge of the mechanics of their movements and, thus, are less able to consciously control their movements when under pressure.

Findings from studies of analogy learning have been interpreted as support for the CPH. Further support for the CPH, or variations on that theme, has been independently provided by several other authors (e.g., Beilock & Carr, 2001; Gucciardi & Dimmock, 2008; Gray, 2004, Wulf, McNevin, & Shea, 2001). For example, Gucciardi and Dimmock provided a direct comparison of CPH and attentional theories of skill breakdown in experienced golfers, and found evidence in support of the former. Participants were required to perform 10 putts in each of three conditions (explicit, irrelevant, and swing thought) under low and high pressure. In the explicit condition, participants were asked to focus on three aspects of the putting movement (e.g., wrist, stance, swing) while performing the 10 shots. In the irrelevant condition, they focused on three cues unrelated to putting (e.g., the colors red, blue, green). The swing thought condition, in some respects, resembled analogical instruction. Participants were asked to focus on a single swing cue, such as “smooth” while putting. Under high pressure, putting error decreased for the swing thought and irrelevant conditions, but increased in the explicit condition. These results were interpreted as support for the CPH, although an attentional argument could not be completely ruled out.
However, evidence disputing the notion that explicit learning results in movement skills that are susceptible to breakdown under pressure has also been reported. Koedijker, Oudejans, and Beek (2007) had participants practice a table tennis forehand shot, using either the right-angled triangle analogy or explicit instruction, over an extended number of practice trials ($N = 10,000$). Early in learning, no differences were found between analogy and explicit learners during nonpressured practice trials, secondary task transfer trials, or pressured trials. This lack of differences was still evident after 10,000 trials, suggesting that explicit learners were not susceptible to the effects of performance anxiety and contrary to predictions of the CPH. In addition, the analogy group’s performance level seemed to plateau after only 1,400 trials. Koedijker et al. argued that the advantages of analogy learning seemed to have disappeared after only a relatively small amount of practice.

The Current Study

To date, investigations of motor learning via analogy have been restricted to table tennis; therefore, the generalizability of the technique to other movement skills is unknown. The primary objective of the current study was to examine the application of analogy learning to a modified basketball shooting task. An analogy commonly used by basketball coaches is to finish the shot as if “your hand is reaching for a cookie from a cookie jar” (e.g., Krause, Meyer, & Meyer, 1999, pp. 72–73). This analogy encourages the correct biomechanical form of the movement and has the effect of imparting backspin on the basketball, which is believed to improve chances of success (Krause et al., 1999). To test the effectiveness of the analogy for preventing skill breakdown under pressure, we had participants perform under stressful, evaluative conditions. We predicted that the performance of analogy learners would not deteriorate under pressure, whereas the performance of explicit learners (provided with a list of traditional instructions) would decline under pressure. We also predicted that analogy learners would be unable to provide a detailed verbal description of the precise mechanics of their movements, but that the explicit learners would report many details.

Implicit learning techniques are thought to lower the amount of attention required to acquire and perform cognitive tasks (e.g., Reber, 1993), but currently little is known about changes in attentional load associated with implicit and explicit motor learning. Secondary tasks are often used to estimate attentional resource capacity during motor performance (e.g., Abernethy, 1988). Previous studies of implicit motor learning have used continuous secondary tasks (e.g., random letter generation; Masters, 1992) that compete with the primary task for attentional resources. Deficits in the performance of the primary task are assumed to represent insufficient allocation of (or competition for) attentional resources, consistent with capacity theories of attention (e.g., Kahneman, 1973). However, continuous secondary tasks preclude the possibility of identifying changes in attentional resource allocation during the movement.

Discrete secondary tasks, such as probe reaction time (PRT), are thought to measure residual attentional capacity after allocation of attention to the primary task (Abernethy, 1988). Probe reaction times are also thought to reflect the effi-
ciency of processing in working memory, with longer PRTs indicating lower efficiency (e.g., Murray & Janelle, 2007; Williams et al., 2002). Probe reaction time therefore provides an indirect measure of the primary task’s attentional requirements and/or processing efficiency. If the primary task consumes large amounts of attentional resources and/or is processed inefficiently, PRTs tend to be slower than if the primary task uses only a small amount of attentional resources and/or is efficiently processed. Current theory suggests that attentional load decreases with practice (e.g., Li & Wright, 2000); therefore, PRT should decrease with practice. It has been argued that analogy learning is less demanding of attentional resources than explicit learning (Liao & Masters, 2001). It follows, therefore, that the PRTs of analogy learners should be shorter than those of explicit learners, both during learning and under pressure.

Several studies have demonstrated that movement preparation places higher demands on attentional resources than movement execution (e.g., Crews & Landers, 1993; Holroyd, Yeung, Coles, & Cohen, 2005). Therefore, longer PRTs were expected during movement preparation, relative to movement execution, in the current study. In addition, it is believed that anxiety places an increased load on attentional resources owing to the processing of negative cognitions (e.g., Baumeister, 1984) and/or task-relevant information (e.g., Masters, 1992). Therefore, PRT should be longer under pressure, relative to nonpressured trials.

Method

Participants

Twenty-four female undergraduate students from the University of Hong Kong volunteered to participate in the experiment. Only female participants were recruited in this study because they are less likely, than boys, to receive formal instructions about one-hand basketball shooting during physical education lessons in Hong Kong. All participants were right hand dominant as assessed by self-report. Upon arrival at the laboratory, participants were randomly assigned to an explicit (n = 12) or an analogy (n = 12) learning condition. Anthropometric and demographic data for both groups were collected (mean age: explicit group M = 21.08 years, SD = 1.16 years and analogy group M = 21.92 years, SD = 1.73 years; mean weight: explicit group M = 53.89 kg, SD = 6.54 kg and analogy group M = 53.80 kg, SD = 9.67 kg; mean height: explicit group M = 1.63 m, SD = .041 m and analogy group M = 1.61 m, SD = .039 m; mean seated height: explicit group M = 1.16 m, SD = .030 m and analogy group M = 1.15 m, SD = .029 m; no significant between group differences were found for any of these measures). Participants were recompensed for their time with an honorarium of HK$250 (approximately US$32). All participants provided informed consent before commencing the experiment. None of the participants had previous experience of basketball free- throw shooting. Ethical approval was granted by the Faculty Ethics Committee.

Design

The experiment consisted of learning and test phases. The learning phase was conducted over two consecutive days, with the test phase conducted on the third
consecutive day. Each day of learning contained six blocks of 40 trials, with 5 min separating each block to allow adequate rest. The test phase was arranged in an A-B-A design (Retention 1—transfer—Retention 2), consisting of one block of 40 trials in each test condition. The retention tests were used to assess learning, whereas the transfer test was used to assess performance under pressure.

**Apparatus**

The primary task required each participant to learn a basketball shooting skill using a standard ball (size 7), while in a seated position (2.76 m from the front of the basket; chair height = 0.5 m) and shooting into a standard basketball rim (circumference = 45 cm) set at a height of 1.75 m. This modified task was adopted to reduce the length of the learning process (because of the shorter shooting distance and lower rim height compared with the regular free throw position) and allow collection of data in a controlled laboratory environment.

Throughout the learning and test phases, attentional load was assessed by simple verbal reaction time to an auditory tone (probe reaction time; PRT). Probes were presented using an auditory tone generator (Deltason Medical Ltd; JS3290) with responses recorded by an analog vibration sensor mounted on the throat (Deltason Medical Ltd; JS3289). Participants were instructed to respond to probes by saying “hai” (Cantonese for “yes”) as quickly as possible after presentation of the tone. For each block of 40 trials, the experimenter manually initiated (push button) presentation of the probe so that 10 probes occurred before initiation of the shooting movement (preparation PRT) and 10 occurred during the shooting movement (execution PRT). Baseline shooting performance was assessed on the remaining trials without probes. Probe and response onset times were recorded at a sampling frequency of 600 Hz using ProReflex Motion Capture (Qualisys; Gothenburg, Sweden) and Qualisys Track Manager Software.

Heart rate was recorded by a Polar Electro Sport Tester (Polar Electro, Finland) comprising a T31 heart rate transmitter attached to a strap around the participant’s chest, and a receiver worn on the wrist. Sampling took place at 5-s intervals. Heart rate was used as a measure of physiological arousal during the test phase (e.g., Hardy & Parfitt, 1991). In addition, an anxiety “thermometer” (Houtman & Bakker, 1989), was used to record self-perceived general anxiety during the test phase. This “thermometer” required participants to place a cross on a 10-cm line to indicate how anxious they had felt during the preceding 40 trials. The left hand end of the line was labeled with “not at all anxious” and the right with “extremely anxious” to give participants a qualitative metric with which to judge their own felt anxiety. Houtman and Bakker reported moderate to high correlations ($r = .64$ to $.77$) between anxiety thermometer score and state anxiety measured by the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, & Lushene, 1970).

**Procedure**

Upon arrival at the laboratory, participants were assigned to one of two experimental conditions (explicit or analogy). A control condition was not included in the design because previous studies have shown that participants in uninstructed
control groups learn to execute their movements in an explicit manner, identical to explicitly instructed groups. Specifically, they report a significant amount of explicit knowledge, and breakdown under conditions that induce anxiety or high cognitive load (e.g., Liao & Masters, 2001; Masters, 1992). Thus, inclusion of a control condition essentially replicates the explicit condition and is, therefore, superfluous to the current investigation.

Participants completed an informed consent form and were then fitted with the analog vibration sensor and the T31 heart rate transmitter. They were then asked to sit comfortably so that baseline PRT (five probes) and heart rate (30 s following 2 min of quiet sitting) could be recorded. No significant differences were found between groups for these two measures (mean heart rate: $t(22) = .21$, $p = .83$, $d = .09$; explicit group $M = 75.11 \text{ bpm}$, $SD = 11.97 \text{ bpm}$ and analogy group $M = 74.12 \text{ bpm}$, $SD = 11.02 \text{ bpm}$; mean baseline PRT: $t(22) = .93$, $p = .37$, $d = .38$; explicit group $M = 424.29 \text{ ms}$, $SD = 67.85 \text{ ms}$ and analogy group $M = 452.25 \text{ ms}$, $SD = 79.71 \text{ ms}$). Before beginning each block of learning trials, participants in the explicit group were given an instruction sheet containing eight written instructions describing the correct technique to perform the shot (Krause et al., 1999). Participants in the analogy group were given a sheet containing the analogy instruction (Table 1). Participants were told to shoot using only the instruction provided and were reminded of the scoring system for the task at the beginning of each day of learning. They were also encouraged to perform to their best ability for both the shooting and PRT tasks, but were informed that probes would not appear on every trial.

During the test phase, participants were reminded to perform to the best of their ability for both the shooting task and the PRT task, but they were not reminded of the explicit or analogy instructions. Participants then performed the transfer test, in which they were told that their shooting mechanics, shooting accuracy, and PRT were to be evaluated by a “basketball expert.” The expert sat in full view of the participant. Participants were informed that they would receive a bonus of HK$50 if they exceeded their highest shooting score and produced their quickest response to the probes, but they would lose HK$10 dollars for each PRT response.

<table>
<thead>
<tr>
<th>Group</th>
<th>Instructions</th>
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<tbody>
<tr>
<td>Explicit</td>
<td>Support ball with the hand of your nonshooting arm.</td>
</tr>
<tr>
<td></td>
<td>Keep forearm vertical before shooting.</td>
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<tr>
<td></td>
<td>Shoulder, elbow and wrist should be in-line with the rim before shooting.</td>
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<td></td>
<td>During shooting, ball should move from below the chin upward and forward in the</td>
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<td></td>
<td>direction of the basket</td>
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<td></td>
<td>Extend elbow fully at ball release.</td>
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<td></td>
<td>Follow-through by snapping wrist forward, so that the palm of shooting hand is</td>
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<td>facing downward.</td>
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<tr>
<td></td>
<td>Release ball with your fingertips.</td>
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<tr>
<td></td>
<td>Hold follow-through (keep wrist firm) until the ball hits the rim.</td>
</tr>
<tr>
<td>Analogy</td>
<td>Shoot as if you are trying to put cookies into a cookie jar on a high shelf.</td>
</tr>
</tbody>
</table>
that was extremely slow (no absolute figure was mentioned) and for every “air ball” (i.e., complete miss). A digital camera was placed behind the participant, with an explanation that it was to record performance during the transfer test so that “quality of movement could be assessed.” However, in reality, no images were recorded. A score board was placed in front of the participants so that they could monitor their overall success/failure. Scores were adjusted by the evaluator. These manipulations were used to increase the importance of performing well in the transfer test and to increase perceived pressure (Baumeister, 1984). Finally, the second retention was carried out to assess enduring attention / performance differences and whether any changes during the transfer test could be attributable to a learning effect.

Heart rate was recorded throughout the test phase and the anxiety “thermometer” (Houtman & Bakker, 1989) was completed immediately following each of the three test blocks (i.e., following Retention 1, transfer, and Retention 2). Following the second retention test, participants were asked to write down any methods, skills, or techniques they remembered using to perform the basketball shooting task (during both learning and test phases). They were encouraged to write as much detail as necessary.

**Analysis and Dependent Variables**

Shooting performance was assessed using a 6-point scale, developed by Hardy and Parfitt (1991), for which 5 was awarded for a “clean” basket, 4 for rim and in, 3 for backboard and in, 2 for rim and out, 1 for backboard and out, and 0 for a complete miss. Hardy and Parfitt reported that the test–retest reliability of this scoring system over a 3-day interval and at different levels of physical fatigue (induced by running) was moderate ($r = .54$). In the current study, Cronbach’s alpha was calculated for each of the 12 learning blocks (no-probe trials only) to assess the reliability of this scoring method using the current data. Reliability was high ($\alpha = .94$), suggesting that the scoring method was consistent over blocks. Mean shooting score for each probe condition (preparation prt, execution prt, and no probe) in each block (i.e., maximum score 5 points) was calculated. Median PRT was calculated for probes rather than the mean to avoid the spurious effects of extremely slow responses and anticipation.

For the learning phase, $Group \times Probe \times Block (2 \times 3 \times 12)$ ANOVAs with repeated measures on the latter two factors were conducted for shooting performance and PRTs. For the test phase, $Group \times Probe \times Block (2 \times 3 \times 3)$ ANOVAs with repeated measures on the latter two factors were used. Greenhouse–Geisser epsilon adjusted probabilities are reported in all cases involving violation of the sphericity assumption. Post hoc tests were conducted when appropriate using simple main effects and $t$ tests with Bonferroni adjustments.

Two independent raters, who were blind to the experimental conditions under which each participant performed, counted the number of explicit rules reported by each participant. Statements were counted as explicit rules if they specifically referred to technical or mechanical aspect of the shooting task (e.g., keep forearm vertical or extend your elbow as you shoot). Statements were excluded if they were irrelevant to task performance, did not refer to technical aspects of the task (e.g., more concentration or the room is hot), or referred to performance of the
PRT task. Because of the high degree of consistency between the two raters (ICC = .91, p < .001), their ratings were averaged to give a single score representing the number of rules reported by each participant.

To derive a score from the anxiety thermometer, the scale was divided into 10 equal parts and a score of 1–10 was assigned depending on where the participant had marked the scale. Higher scores represented greater perceived anxiety. Since anxiety should be equivalent during the two retention tests, Cronbach’s alpha was calculated as a measure of reliability for the anxiety thermometer. The score was high (α = .81), suggesting that the scale is a reasonably reliable and consistent measure of anxiety. Mean and maximum heart rates during each test served as an objective measure of physiological arousal. Anxiety thermometer score, mean heart rate, and maximum heart rate during the three test phase blocks were analyzed using a Group × Block (2 × 3) MANOVA with repeated measures on the latter factor. Again, simple main effects and t tests with Bonferroni adjustments were used following the discovery of significant main effects or interactions. Eta squared was used as a measure of multivariate effect size with values above .14 indicating large effects, values above .05 moderate effects, and below .05 small effects (Cohen, 1988). Cohen’s d is used to represent effects size between two means with values above .80 representing large effects, above .40 moderate effects, and all other values small effect size.

Results

Learning Phase: Shooting Performance

The three-way ANOVA showed only a main effect of block, $F(4.32, 242) = 21.10, p < .001$, $\eta^2 = .49$, and an interaction between probe and block, $F(10.28, 484) = 1.97, p < .05$, $\eta^2 = .08$. Pairwise comparisons revealed that performance during later learning blocks (Block 9: $M = 2.94, SD = .47$; Block 10: $M = 2.97, SD = .56$; Block 11: $M = 3.11, SD = .48$; Block 12: $M = 3.17, SD = .40$) was significantly better than during earlier learning blocks (Block 1: $M = 2.02, SD = .75$; Block 2: $M = 2.42, SD = .58$; Block 3: $M = 2.47, SD = .70$; all $p < .01$, Cohen’s $d$ ranged from .79 to 1.91), suggesting that learning was equivalent for both groups (Figure 1); however, it proved impossible to isolate the Probe × Block interaction using the appropriate adjustment to alpha level (Figure 2). Consequently, performance during the learning phase is illustrated in Figure 1 as a function of group and block only.

Learning Phase: PRT

Analysis of PRTs revealed a significant block effect, $F(3.14, 242) = 4.21, p < .05$, $\eta^2 = .16$; probe effect, $F(1, 22) = 4.38, p < .05$, $\eta^2 = .17$; and an interaction between probe and block, $F(4.91, 242) = 5.28, p < .001$, $\eta^2 = .19$. Pairwise comparisons (all $p < .05$) showed that PRT performance in the first learning block ($M = 526.64$ ms, $SD = 63.87$ ms) was significantly slower than during Blocks 7 ($M = 472.71$ ms, $SD = 66.52$ ms, $p = .01$, $d = .83$) and 8 ($M = 473.26$ ms, $SD = 69.18$ ms, $p = .03$, $d = .80$), suggesting that attentional load imposed by the motor task declined over the learning phase. Overall, preparation PRT ($M = 503.31$ ms, $SD =$
Figure 1 — Mean shooting performance of analogy and explicit groups across learning and testing blocks.
Figure 2 — Mean shooting performance in different probe conditions across learning and testing blocks.
71.64 ms) was significantly longer than execution PRT ($M = 483.05$ ms, $SD = 72.44$ ms), suggesting that more attention was devoted to movement preparation than to movement execution. The interaction effect was isolated to a significant change in execution PRT over blocks, $F(4.14, 95.13) = 7.80, p < .001$, $\eta^2 = .25$, but no change to preparation PRT over blocks, $F(3.09, 70.98) = 2.12, p = .10$, $\eta^2 = .08$; see Figure 3.

**Effectiveness of Pressure Manipulation**

A Group $\times$ Block (2 $\times$ 3) MANOVA with repeated measures on the latter factors revealed a significant effect of Block only, $F(6, 16) = 14.22, p < .001$, $\eta^2 = .84$. Anxiety thermometer, mean heart rate, and maximum heart rate all increased during the pressured transfer test. These results imply that the pressure intervention successfully increased participants’ anxiety levels. Table 2 shows the mean (and standard deviation) anxiety thermometer scores, maximum heart rate, and mean heart rate for each of the test phase blocks and for both groups.

**Test Phase: Shooting Performance**

Analysis revealed a significant main effect of probe, $F(1.57, 44) = 3.68, p < .05$, $\eta^2 = .14$, and an interaction between group and block, $F(2, 44) = 4.22, p = .02$, $\eta^2 = .16$. Pairwise comparisons of the probe effect indicated that shooting performance on trials when the probe was presented before movement initiation ($M = 2.99$, $SD = .45$) was poorer than on trials that were not probed ($M = 3.11$, $SD = .39$; see Figure 2); however, with the adjustment to alpha, this difference was not significant ($p = .09$). No other significant differences were found.

Examination of Figure 1 suggests that the performance of both groups changed over blocks, albeit in different directions. Pairwise comparisons demonstrated that the explicit group’s performance during the transfer test ($M = 59.66$, $SD = 5.85$) was poorer than during Retention 1 ($M = 63.29$, $SD = 7.64$; $t(11) = 2.62, p = .02, d = .54$), whereas the analogy group’s performance during the transfer test ($M = 64.04$, $SD = 7.17$) was not significantly different to Retention 1 ($M = 59.58$, $SD = 5.12$; $t(11) = 2.01, p = .07, d = .72$). In addition, independent $t$ tests were used to assess any group differences during the test phase; no significant differences were found ($p > .10$ in all cases). Thus, under pressure the analogy group demonstrated a modest, but nonsignificant increase in their performance whereas the explicit group suffered a significant drop in performance, although neither group enjoyed an overall performance advantage.

**Testing Phase: PRT**

Analysis of PRTs during the test phase revealed significant effects of block, $F(2, 44) = 6.89, p < .01$, $\eta^2 = .24$; probe, $F(1, 22) = 5.69, p < .03$, $\eta^2 = .21$; and an interaction between probe and block, $F(2, 44) = 3.34, p = .04$, $\eta^2 = .13$. Pairwise comparisons of the block effect indicated that PRTs increased significantly during transfer ($M = 481.43$ ms, $SD = 72.79$ ms, $p = .02$, $d = .30$) and during the second retention test ($M = 483.98$ ms, $SD = 68.60$ ms, $p = .01$, $d = .34$) relative to the first retention test ($M = 460.03$ ms, $SD = 72.14$ ms; see Figure 3). There was no signifi-
Figure 3 — Execution and preparation probe reaction times (PRT) of analogy and explicit groups across learning and testing blocks.
Analogy and Performance Under Pressure

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...cant PRT difference between transfer and the second retention test \(p > .05\). Further examination of the probe effect revealed that preparation PRT \((M = 490.21\text{ ms, } SD = 76.07\text{ ms})\) was significantly slower than execution PRT \((M = 460.09\text{ ms, } SD = 66.29\text{ ms})\).

Further examination of the Block \(\times\) Probe interaction showed that there was a significant block effect for preparation PRT, \(F(2, 46) = 9.09, p < .001, \eta^2 = .28\), but not for execution PRT, \(F(2, 46) = 1.69, p > .05, \eta^2 = .07\). Preparation PRTs during transfer \((498.91\text{ ms, } SD = 79.77\text{ ms}; p = .02, d = .42)\) and during the second retention test \((503.58\text{ ms, } SD = 80.45\text{ ms}; p = .01, d = .48)\) were significantly slower than during the first retention test \((468.14\text{ ms, } SD = 67.98\text{ ms})\). Execution PRTs were uniform across the test phase (Retention 1 = 451.93 ms, SD = 76.30 ms; transfer = 463.95 ms, SD = 65.82 ms; Retention 2 = 464.37 ms, SD = 56.75 ms). These results suggest that both groups devoted more attentional resources to the preparation of their movements during the pressured transfer test and subsequent retention test.

**Verbal Knowledge**

An independent samples \(t\) test revealed that the analogy group reported less explicit verbal knowledge than the explicit group, \(t(22) = 5.82, p < .001, d = 2.38\). The mean number of task-relevant rules reported by the analogy and explicit groups were 1.88 \((SD = 1.28)\) and 6.17 \((SD = 2.21)\), respectively.

**Discussion**

Analogy instructions are thought to promote acquisition of task parameters in an implicit, as opposed to an explicit, fashion (Law et al., 2003; Liao & Masters, 2001; Masters, 2000). We adopted a cookie jar metaphor to examine analogy learning in a modified basketball shooting task, and predicted that analogy learners would have less reportable knowledge of their movement mechanics and shorter PRT, relative to explicit (instructed) learners. We also predicted, based on...
Masters’s (1992) conscious processing hypothesis that, unlike explicit learners, analogy learners would show stable performance when placed under pressure.

Throughout the learning phase and two retention tests, analogy and explicit learners performed at comparable levels, suggesting that neither method is more effective than the other for nonpressured performance. During the pressured transfer test, heart rate and self-reported anxiety increased for both groups, confirming the effectiveness of the pressure manipulation. The analogy group’s performance also increased (albeit nonsignificantly); however, the performance in the explicit group deteriorated. In addition, explicit learners were able to report more aspects of their movements than analogy learners, suggesting that the latter had acquired their skill in a predominantly implicit fashion. These results are consistent with previous research that has shown equivalent performance and learning following analogy and explicit instruction (Liao & Masters, 2001; Poolton, Masters, & Maxwell, 2006), and robust performance under pressure for analogy learners, but not explicit learners (Law et al., 2003; Experiment 2, Liao & Masters, 2001).

However, the current results contradict the findings of Koedijk et al. (2007), who found no differential effects of pressure on analogy and explicit learners. Unfortunately, several problems existed in their study that render the findings problematic. First, the increases in anxiety reported by Koedijk et al.’s participants were relatively small compared with the current results and may have been insufficiently taxing to evoke performance breakdown in either the analogy or explicit groups. In addition, table tennis balls were served at an average rate of 60 per minute, leaving little opportunity for conscious processing (Beilock, Bertenthal, McCoy, & Carr, 2004).

Previously, it has been argued that learning by analogy places a lighter load on working memory resources (specifically, the central executive and phonological loop), because of the reduced volume of verbal information to be processed relative to explicit instructions (Masters, 2000). Lessening the load on the central executive and phonological loop potentially “frees up” these resources for the completion of other tasks. Evidence to support this claim was drawn from a number of experimental results that demonstrated that analogy learners were unaffected by the imposition of a verbal working memory task when performing (e.g., Poolton et al., 2006). However, Poolton et al. conceded that analogies and explicit instructions may be processed in different subsystems of working memory. Specifically, explicit instructions may be processed primarily in the central executive and phonological loop, whereas analogies may be processed as a visual image primarily in the visuo-spatial sketchpad, because the movement described by an analogy is designed to be easier to visualize than a set of explicit rules (for a related argument, see Annett, 1993). Whichever of these explanations proves correct, lessened loads on the verbal subsystems of working memory should, in principle, be reflected in shorter vocal PRT.

No differential pattern of responses to probes was found between groups, suggesting that an equivalent amount of attention or mental effort was committed to the task. For both groups, preparation PRTs were slower than execution PRTs. This finding was also reported by Holroyd et al. (2005), who suggested that movement preparation, rather than online control (movement execution), requires a substantial contribution from cognitive (attentional/working memory) resources.

The PRT of both groups increased under pressure, albeit for movement preparation only. However, despite committing greater attentional resources under
pressure, participants in the explicit group did not maintain their shooting performance (participants in the analogy group did). This finding is not entirely compatible with a working memory or attentional load explanation (cf. Gucciardi & Dimmock, 2008), because shorter PRT for the analogy group would be expected. An alternative explanation seems more plausible. The CPH (Masters, 1992) suggests that the processing of explicit rules causes breakdown in skilled performance under pressure. It follows that the extent of breakdown might be correlated with the amount of explicit knowledge. One of the main differences between the two groups in the current study was the amount of explicit knowledge that they reported, with the explicit group reporting significantly more knowledge than the analogy group. This supports the idea that it is the processing of explicit task knowledge that may be crucial to performance breakdown, consistent with the predictions of the CPH, rather than simply the load on attention.

Previous work (e.g., Maxwell et al., 2006) has shown a direct relationship between number of explicit rules and decrease in performance under pressure, such that performance decline is greater when explicit knowledge of movement characteristics is high. Correlations between amount of verbal knowledge and breakdown in performance under pressure in the current study might also indicate a negative relationship between the two (i.e., greater decrement in performance associated with more explicit knowledge), and provide additional support for the CPH. However, analogy learners typically reported only the analogy and explicit learners only reported the rules provided to them. Thus, in both cases a zero correlation was evident. Future studies could use a discovery learning condition to investigate the relationship.

Other studies have pitted CPH against Eysenck and Calvo’s (1992) PET (see Wilson, 2008), with results supporting the latter, rather than the former, explanation of performance breakdown. The longer PRTs in the current study might be interpreted as indicating reduced processing capacity in working memory, despite any increased effort. Skill breakdown could then be viewed as the result of processing of multiple explicit rules. However, if this explanation is correct, we would also expect shorter PRTs for the analogy group, relative to the explicit group, during nonpressured retention tests. No such differences were found. Since previous studies used within-subject designs and did not manipulate the amount of explicit knowledge available to participants, the CPH cannot be discounted outright. A more parsimonious explanation is that performance breakdown is a result of both quantity of information processed in working memory, on-task effort, and type of information processed by the performer. A merging of PET (or ACT) with CPH, therefore, seems a reasonable ambition for future research. However, this might necessitate the curious paradox of viewing explicit knowledge of task performance as irrelevant information, most obviously for skills that have become automatized.

Limitations and Future Research

Although the mounting evidence in support of the use of implicit motor learning strategies to prevent choking under pressure is quite convincing, there are several limitations that must be addressed by future research. First, alternative (multidimensional) measures of anxiety should be used to identify whether different types
of anxiety (i.e., cognitive or somatic) have differential effects on performance and processing. It is plausible, for example, that analogy learners are resistant to both whereas explicit learners are not (see Poolton, Masters, & Maxwell, 2007).

Research on the acquisition of motor skills via analogy has been restricted to only two skills—the table tennis forehand and now modified basketball shooting (direct applications to wheelchair basketball are obvious). These are single tasks performed in relative isolation of others skills that comprise competitive table tennis or basketball. It is currently unknown whether multiple skills can be acquired, each with their own analogy. The use of analogy instructions has also been limited to novices. It is plausible that experts who are susceptible to choking under pressure might also benefit from this kind of instruction. The analogy may help to chunk or consolidate experts’ knowledge into a single “rule.” Alternatively, the analogy may act as a simple performance cue, perhaps as part of a preshot routine, that distracts attention away from the mechanics of the movement.

Although we have argued for a conscious processing explanation for our results, the evidence is indirect. A direct measure of cognitive processing during the task would provide better evidence. We could ask participants to articulate what they are thinking concurrently with performance or provide retrospective reports at randomly selected points during their performance. However, each of these processes has its own problems (see Ericsson & Simon, 1984). An alternative technique might be to measure cortical activity (e.g., electroencephalography). For example, if skill breakdown is associated with explicit rule use, there should be more brain activity around the temporal lobe during pressured relative to nonpressured trials. The temporal lobe is believed to be associated with verbal rule processing (Jueptner et al., 1997). Although this technique could only be used before movement execution when the performer is standing still (see Crews & Landers, 1993), the PRT results of the current study suggest that this is precisely the period when active processing is most likely, and we predict that analogy learners will exhibit lower activity than explicit learners.

Conclusions

The current study extended previous work by focusing on performance of a self-paced task, rather than an externally paced task, over several days of practice, and under pressured conditions. In addition, attentional requirements are measured at different stages of learning, at selected points during task execution (before and following movement initiation), and under varying levels of performance pressure. In summary, it appears that acquisition of motor skills by analogy may stabilize performance under pressure; however, longitudinal studies of the type conducted by Koedijker et al., (2007) are required to confirm the durability of this effect. Analogy learning is a simple and efficient method of coaching because it reduces the amount of information that must be processed to a bare minimum. It may, therefore, also be useful for teaching children or individuals with cognitive disorders that restrict their ability to process explicit instructions (for similar recommendations, see Hodges & Franks, 2004; Maxwell, Masters, & Hammond, 2008).
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