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# The influence of analogy learning on decision-making in table tennis: Evidence from behavioural data

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## Abstract

*Objectives:* In sports it may be necessary for a performer to make a decision and execute a movement in close succession, or even concurrently. The manner in which a movement is controlled may impact on the degree to which the performer is able to combine decisions and movements effectively. Previous work has shown that if control of the movement has been acquired explicitly, with a high declarative knowledge content, dual-task conditions can be disruptive to performance of the movement. Previous work has also shown that, in contrast, if movement control is acquired by analogical instruction, with a low declarative knowledge content, motor performance is unaffected by dual-task conditions. It was, therefore, hypothesised that analogy learning will reduce the performance cost associated with processing motor responses while making high-complexity decisions.

*Methods:* Participants learnt to hit a table tennis topspin forehand using either a single analogical instruction or a set of written instructions (explicit learning). Motor performance was assessed when decisions about the direction in which to hit the ball were either low in complexity or high in complexity.

*Results:* Low-complexity decisions had no effect on motor performance in either condition. However, high-complexity decisions caused a relative performance deterioration in the Explicit condition, but not in the Analogy condition.

*Conclusions:* These findings extend the implicit motor learning literature by highlighting the role of analogy learning in the complex interaction between decision-making and movement control in sport.

*Keywords:* Analogy learning; Implicit motor learning; Decision making; Declarative knowledge

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## Introduction

In order to develop an individual's motor skill, the sports coach must communicate instructions that are understandable and reproducible. One technique is to provide the learner with an analogy that disguises many of the technical rules, ordinarily provided by explicit instruction, in a single biomechanical metaphor of the movement (Masters, 2000). For example, a basketball player may be told to put his/her hand in the cookie jar when shooting or a golfer may be instructed to swing the club like a pendulum when putting. As a result, analogy learners demonstrate less access to declarative knowledge about the movement than explicit learners (Law, Masters, Bray, Eves, & Bardswell, 2003; Liao & Masters, 2001; Poolton, Masters, & Maxwell, 2005a). This characteristic has consistently been shown in the implicit motor learning literature (see Masters & Maxwell, 2004 for a review). Consequently, analogy learning has been recommended as a practical alternative to ecologically challenged implicit motor learning paradigms that generally are difficult to apply in the field and result in slower learning than normal (e.g., dual-task learning—Hardy, Mullen, & Jones, 1996; Masters, 1992; Maxwell, Masters, & Eves, 2000; no-feedback learning—Maxwell, Masters, & Eves, 2003; subliminal learning—Masters, Maxwell, & Eves, 2001). Investigations of learning by analogical instruction have shown the technique to allow robust motor performance even when a demanding cognitive task, such as counting backwards in three's, is performed concurrently (Liao & Masters, 2001; Poolton et al., 2005a). Normally, such a task will interfere with motor performance, especially if the individual has accumulated a large pool of explicit (declarative) knowledge of the task.

In sport, successful performance may not solely rely on proficient movement control. An effective decision on the motor response to be produced may also be required. For this, the performer may adopt decision-making strategies; for example, in an effort to successfully anticipate the direction of a tennis serve, a player may try to recognise consistent patterns in an opponent's service strategy or become aware of movement idiosyncrasies associated with different serves (McPherson, 1993). At times, the temporal constraints of the environment require the processing of both a decision and a movement in close succession, or even concurrently (Bard, Fleury, & Goulet, 1994). In such a situation, decision-making might be regarded as an additional cognitive task, and therefore, may cause a disruption in the motor performance of explicit learners. Learning by analogy may overcome this problem, as motor performance is perturbed less by additional cognitive loads.

If decision-making does interfere with explicit learners' movement execution, the extent of the disruption may be dependent on the complexity of the decision. Raab (2003) argued that decisions high in complexity are better served by intentional (explicit) learning of if–then rules, whereas decisions low in complexity are better learnt incidentally (implicitly). He investigated decision complexity in a series of four experiments that simulated tactical decision-making in ball games. He had novice participants learn the relationship between a visually presented game situation and the corresponding tactically astute responses (decision) normally made by experts. Participants either received instructions and video demonstrations of decision-making rules (explicit learning) to promote intentional learning, or memorised decisions made by a marked player in the visual display. The memory task served as a cover story to promote incidental (implicit) learning of decision-making rules. Decision-making performance was tested in an interactive simulation of a game situation, in which participants assumed the role of the playmaker and made decisions in 'real-time' at the end of a video clip by moving in the direction of the planned motor performance. When the decision learnt was low in complexity (Experiments 1 and 2), participants who learnt implicitly had superior decision-making performance. However, an increase in complexity, by manipulation of the perceptual and cognitive elements of the task (Experiments 3 and 4), resulted in superior decision-making performance by participants who learnt explicitly. Raab concluded that implicit learning is advantageous when a decision has low complexity, whereas explicit learning is beneficial when a decision has high complexity. The findings imply that high-complexity decisions benefit more from an intentional attempt by the performer to solve the cognitive problem than low-complexity decisions. The processing of low-complexity decisions may, therefore, require minimal attention and not interfere with explicit learners' motor performance as only movement need be controlled; however, high-complexity decisions may be disruptive, as performers must attend to both the decision and the motor response.

The present experiment was designed to investigate the effect of making low- and high-complexity decisions on motor skill execution. Moreover, the experiment examined whether potential performance costs associated with dual-task performance are alleviated by analogy learning. Consistent with Liao and Masters (2001), participants learnt a table tennis topspin forehand by referring to either a set of task-relevant instructions (explicit motor learning) or a single analogical instruction. Instructions were introduced in the explicit learning condition to encourage the active testing of hypotheses to overcome performance errors and the storage and retrieval of declarative knowledge. The analogical instruction that was used has recently been shown by Poolton et al. (2005a) to produce motor performance (within a Chinese population) that is robust to concurrent processing of a cognitive task (counting backwards in seven's). The analogy simply instructed participants to 'move the bat as if it is travelling up the side of a mountain'.

Following learning, participants were required to perform the motor skill in response to decisions that were either low or high in complexity. Low-complexity decisions required a simple stimulus–response match, whereas high-complexity decisions were dependent on a predetermined sequence. The sequential nature of this task was expected to require the on-line processing and storage of information (Baddeley, Chincotta, & Adlam, 2001; Beilock & Carr, 2005). Between-group differences were not expected in the motor responses to low-complexity decisions; however, differences were expected in response to high-complexity decisions as a consequence of their greater processing demands. Specifically, motor performance of explicit learners was expected to deteriorate, whereas performance of analogy learners was expected to remain robust.

## Method

### *Participants*

Thirty-five participants (*M* age = 20.5 years, *SD* = 3.39) participated in the experiment. Informed consent was provided by participants, who received HK$100 (approximately €9.5). All participants were right-hand dominant novices to table tennis. Classification as novice was based on having only ever played table tennis less than once each month and having received no formal coaching. The participants were randomly assigned to either an Analogy ($n = 17$) or an Explicit treatment condition ($n = 18$). Two participants in the Analogy condition were withdrawn from analysis ($n = 15$) because they were subsequently discovered to have extensive experience in activities that may have confounded learning (e.g., tennis, squash).

### *Apparatus*

The experiment was performed on a standard table tennis table. At the end of the table opposing the participant, six large squares (50 cm wide) were marked, in two rows (Fig. 1). Each square in the row furthest from the participant housed a target (concentric square: 25 cm wide). During the Learning Phase of the study, the target was the square numbered 2 (Fig. 1); three points were awarded for hitting the ball into this area. Hitting the ball into the square housing the target numbered 5 resulted in a score of two points. One point was given to any ball that landed in any other part of the marked area. During the Test Phase, the targets on the left or right third of the table were used (numbered 1 and 3, respectively). Again, three points were awarded for a ball that landed on the target and two points for a ball that landed in the square housing the target (squares 4 and 6, respectively). One point was awarded for balls that landed in the area surrounding this square. Balls that were hit to the incorrect side of the table, or missed the marked area, scored zero. Thus, for a ball that was required to be hit to the right-hand target (Target 3), a score of one point was awarded if it landed on squares numbered 2, 5, 8 or 9 and a score of zero was awarded if it landed on squares 1, 4 or 7.

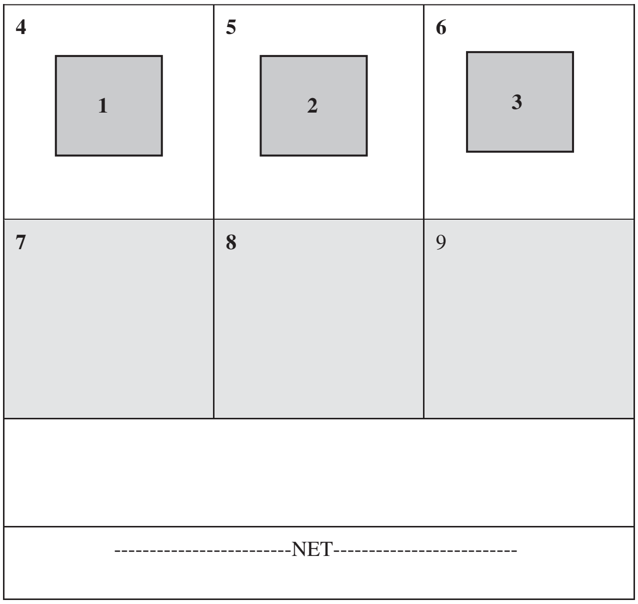

Fig. 1. Marked area on the side of the table opposing the participant. The central target (numbered 2) was used in learning, while the outer targets (numbered 1 and 3) were used in the Test Phase.

A Newgy Robo-pong 2000 table tennis ball server supplied 40 mm balls, with backspin, down the centre line of the table at a frequency of 30 balls/min. Balls rose to a peak height of approximately 20 cm at the table's edge. One hundred balls in total (50 white and 50 yellow) were placed in the collecting trough of the machine and were mixed regularly so that the colour of ball that was served was random. The server was adapted to prevent the identification of ball colour until after ball release. Participants used a Donic Waldner 500 table tennis bat.

## *Procedure*

The experiment was partitioned into a Learning Phase followed by a Test Phase. Learning comprised of 300 trials in 15 20-trial blocks. Participants were instructed to hold the bat using a western 'shake hands' grip (Sneyd, 1994). In the Explicit condition, participants were given six task-relevant instructions (Table 1). In the Analogy condition, participants received a single analogical rule: 'move the bat as if it is travelling up the side of a mountain' (Poolton et al., 2005a). Participants were asked to use the instructions to hit topspin forehand shots so that the ball landed in the central target (Fig. 1: Target 2). At no point was the technique of a topspin forehand demonstrated or feedback given about the correctness of technique. Participants were reminded of the instructions prior to each block of trials. If a participant failed to hit topspin during a block of trials (adjudged by the experimenter) a diagram was shown that demonstrated the appropriate ball rotation.

Following the Learning Phase, participants completed a Declarative Knowledge Protocol which required the report of any movements, methods or techniques that participants remembered using while performing the task.

Table 1
Instructions given to the Analogy condition and the Explicit condition in English, and the subsequent translation into Chinese

| Instructions | English | Cantonese |
|---|---|---|
| Explicit condition[a] | 1. Keep your feet a little wider than shoulder width apart | 1. 雙腿分站，距離比肩膊稍寬。 |
| | 2. Position your feet behind the table with the right foot furthest from the table | 2. 雙腳站於球桌後，左腳前，右 後。 |
| | 3. Move the bat backwards and down | 3. 把球拍拉向後下方。 |
| | 4. Move your body weight to the front leg | 4. 把身體重心由後腳移至前腳。 |
| | 5. Move your playing arm forwards and upwards | 5. 拉動執拍手臂向前上方。 |
| | 6. Keep the bat face at a vertical angle | 6. 拉動時，保持球拍面垂直。 |
| Analogy condition | Move the bat as if it is travelling up the side of a mountain | 擊乒乓球時球拍移動如沿著山腳上山頂一樣。 |

[a] Instructions for the Explicit condition were taken from Sneyd (1994) and The Sport Council (1995).

The Test Phase comprised of two decision-making tests in which ball colour signified the target to which the ball should be hit. The first test was low in complexity (low-complexity test). Participants were required to hit white balls to the target on the right and yellow balls to the target on the left. Prior to motor performance, participants' ability to make the correct decision was evaluated in a 20-trial block (decision-only test). Standing at the end of the table, participants were asked to verbally report the direction in which each ball should be hit. Participants then performed two 20-trial motor performance/decision-making blocks.

The second decision-making test was relatively more complex (high-complexity test). The target signified by ball colour alternated after every two balls. For trials 1 and 2, participants were required to hit white balls to the target on the right and yellow balls to the target on the left (as in the low-complexity test). In trials 3 and 4, the ball colour–target representation switched, such that, white balls were now hit to the target on the left and yellow balls were hit to the target on the right. Trials 5 and 6 reverted back to white–right and yellow–left. Trials 7 and 8, white–left and yellow–right, and so on. The high-complexity test replicated the format of the low-complexity test. Participants performed the 20-trial decision-only test and then completed two 20-trial motor performance/decision-making blocks. If at any time during the high-complexity test participants forgot the correct ball colour sequence, they notified the experimenter, missed the next ball, and resumed task performance from the original starting sequence (first two balls, white balls hit to the target on the right). On completion of the task, participants were debriefed and paid.

### *Analysis*

Total score in each block (maximum score 60 points) was taken as the dependent variable in the Learning Phase. In the Test Phase, the decision complexity manipulation was assessed by totalling the number of correct decisions made in each of the decision-only and motor performance tests. Assessment of motor performance, when making low- or high-complexity decisions, was performed by calculating participants' performance score, per correct decision, in each block of the Test Phase. This dependent variable was preferred as it removed the possibility of results being confounded by a decision versus motor performance trade off. Motor and decision-making performance was analysed by multivariate analysis of variance (MANOVA) with repeated measures, reporting Wilks' Lambda probabilities. Using multivariate analysis for repeated measures avoids assumptions of sphericity, specifically, compound symmetry of the variance–covariance matrix, and is advised by a number of authors (e.g., Howell, 1997; Tabachnick & Fidell, 2000).

In the high-complexity test, participants were asked to verbally report incidents in which the ball sequence of the task was forgotten. However, on occasion, unknowingly participants appeared to forget the order of the sequence. Typically, a succession of correct decisions would be followed by a series of erroneous decisions. However, the order of the erroneous decisions was not arbitrary. It appeared that participants inadvertently skipped a ball in the sequence, continuing the sequence from the next ball. Consequently, the participants sequence was not in 'sync' with the experimental ball sequence. Performance scores, therefore, did not necessarily reflect participants' task competence. To reduce the possibility of this effect, the ball on which the sequence was 'skipped' was identified by the experimenter, and performance was rescored from this point. Due to the subjectivity of this process, a second rater rescored the number of correct decisions made in the high-complexity test. Intraclass Correlation Co-efficients (ICC) showed significant correlations between the independent raters in their scoring of correct decisions made in both the decision-only ($\mathrm{ICC} = .95$, $F\ (32) = 19.35$, $p<.001$) and motor performance tests ($\mathrm{ICC} = .94$, $F\ (32) = 16.52$, $p<.001$), confirming the accuracy of the primary rater's scoring.

The amount of information reported in the Declarative Knowledge Protocols, relating to the mechanics of motor performance (e.g., 'I moved my body weight from the back to the front leg' or 'I tried to find the best bat angle'), was evaluated by two independent raters. There was a significant correlation between the two raters scores ($\mathrm{ICC} = .95$, $F\ (32) = 20.31$, $p<.001$). Accordingly, the mean score of the independent raters was calculated for analysis.

## Results

### *Learning phase*

Hitting accuracy during learning was assessed by computing a Group × Block ($2 \times 15$) MANOVA with repeated measures. No effect of Group ($F\ (1,\ 31) = .19$, $p = .67$, $\eta^2 = .01$) was shown, but a main effect of Block (Wilk's $\Lambda = .18$, $F(14, 18) = 5.90$, $p<.001$, $\eta^2 = .82$) and an interaction (Wilk's $\Lambda = .34$, $F(14, 18) = 2.50$, $p<.05$, $\eta^2 = .66$) were evident. Inspection of Fig. 2 suggests that both the Analogy and Explicit conditions improved in the Learning Phase, implying learning. Analysis of simple main effects confirmed this observation, showing a significant Block effect in each condition ($p<.005$). The interaction is accounted for by the crossover of performance scores in the two conditions during learning, but no significant differences were present in either the early stages of learning or by the end of learning ($p>.05$).

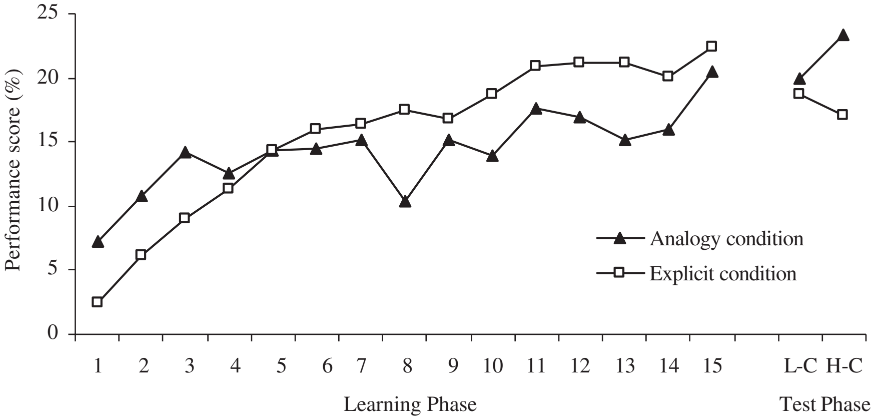

Fig. 2. Analogy and Explicit conditions motor accuracy in the Learning Phase and the Test Phase. Performance score per correct decision is shown for the Low-Complexity (L-C) and High-Complexity (H-C) tests.

### *Test phase*

#### *Decision-only test*

A Group × Decision (2 × 2) MANOVA with repeated measures was computed to assess performance in the low- and high-complexity decision-only tests. Neither a main effect of Group ($F(1,31) = .001$, $p = .97$, $\eta^2 = 0$) nor an interaction (Wilk's $\Lambda = .96$, $F(1,31) = 1.34$, $p = .26$, $\eta^2 = .04$) was shown; however, a significant effect of Decision (Wilk's $\Lambda = .20$, $F(1,31) = 125.20$, $p<.001$, $\eta^2 = .80$) was evident. A lower percentage of correct decisions were made in the high-complexity decision-only test ($M = 74.39\%$) than in the low-complexity decision-only test ($M = 98.03\%$), indicative of a successful complexity manipulation.

#### *Motor performance*

Motor performance when making low- versus high-complexity decisions was assessed by a Group × Block (2 × 2) MANOVA with repeated measures. Neither a main effect of Group ($F(1,31) = 1.59, p = .22, \eta^2 = .05$) nor of Block (Wilk's $\Lambda = .98, F(1,31) = .69, p = .41, \eta^2 = .02$) was shown; however, a significant interaction (Wilk's $\Lambda = .88$, $F(1,31) = 4.29$, $p<.05$, $\eta^2 = .13$) was evident. Inspection of Fig. 2 suggests that performance during low-complexity decisions was not different, but that transfer to a high-complexity decision task had a differential effect on the treatment conditions. Motor performance of participants in the Explicit condition deteriorated when highly complex decisions were required, whereas performance of participants in the Analogy condition improved.

Analysis of the number of correct decisions made during the low- and high-complexity tests showed no significant effect of Group ($F(1,31) = 1.01, p = .34, \eta^2 = .03$) or an interaction (Wilk's $\Lambda = .94$, $F(1,31) = 1.99$, $p = .17$, $\eta^2 = .06$); although a main effect of Block (Wilk's $\Lambda = .21$, $F(1,31) = 120.22, p<.001, \eta^2 = .80$) was evident. Participants made more correct decisions in the low-complexity test ($M = 94.15\%$) than in the high-complexity test ($M = 73.10\%$).

#### *Declarative knowledge protocol*

The amount of knowledge relevant to the motor skill reported by participants in the two conditions was analysed by an independent samples *t*-test. A significant between-group effect ($t(31) = -3.79$, $p<.001$, $\eta^2 = .32$) was shown. Not surprisingly, participants in the Explicit condition reported more motor performance information ($M$ rules = 5.25) than participants in the Analogy condition ($M$ rules = 3.07) following the Learning Phase.

## **Discussion**

This experiment examined the interaction between decision-making and movement control, asking whether the potential performance cost associated with concurrent processing of a decision and a movement can be alleviated by learning the movement component by analogical instruction. Participants learnt a table tennis topspin forehand via six task-relevant instructions (Explicit condition) or via a single analogical rule (Analogy condition). While the 300-trial Learning Phase resulted in similar rates of motor skill acquisition, the two conditions differed in the amount of task-relevant knowledge explicated in the Declarative Knowledge Protocol following learning; participants in the Analogy condition explicated few movement-related rules, suggesting that they had less access to declarative knowledge of the task for on-line control of movement.

In the decision-only test, participants made more correct decisions when the decision was low in complexity than when it was high in complexity, a finding also evident in the motor performance/decision-making tests. This implies that the high-complexity test was more difficult, and thus, carried a greater information processing load than the low-complexity test. As a result, when the decisions were low in complexity, no motor performance differences were evident between the two conditions, whereas when the decisions were high in complexity, the performance of participants in the Explicit condition deteriorated relative to participants in the Analogy condition. The finding suggests that participants in the Explicit condition had difficulty in effectively processing both a high-complexity decision and a motor response. In contrast, analogy learners were able to perform both the decision and motor tasks effectively.

This experiment highlights the importance of considering the cognitive demands of the entire task in sport, especially, if the performer must make a decision that requires an immediate motor response. Analogy learning appears to be a practical means to reduce the performance costs that occur in circumstances that require highly complex decisions in tandem with motor responses. However, identifying the mechanism that sets apart the treatment conditions is beyond the scope of the experimental design. To speculate, it has been argued that disruption of the motor performance of explicit learners under dual-task conditions is a consequence of their dependence on working memory to implement instructions (Masters, 2000; Maxwell et al., 2003), develop and test hypotheses, accrue task-relevant declarative knowledge (Maxwell, Masters, Kerr, & Weedon, 2001; Poolton, Masters, & Maxwell, 2005c), and retrieve knowledge for on-line control of movement (Maxwell et al., 2003). Working memory, as developed by Baddeley and colleagues (for an extensive review see Baddeley, 1999), is a limited capacity system which can be over-extended by the requirement to process both a cognitive task and a movement. The absence of disruption to motor performance in analogy learners under dual-task conditions implies that control of the movement is independent of working memory (Maxwell et al., 2003). Analogy learning, therefore, may liberate working memory resources from motor control for use in other performance-related tasks, such as decision-making.

However, it may be erroneous to categorise analogy learning as working memory independent on the basis of robust performance under dual-task conditions. Unlike standard implicit (motor) learning paradigms (e.g., Masters, 1992), analogy learners are presented with an explicit instruction and learning is typically intentional. These are both characteristics of explicit learning. Explicit instructions are assumed to be implemented and monitored by the central executive component of working memory (see Baddeley (1996) for a review on the central executive); hence, performance of explicit learners tends to be disrupted when the central executive is loaded by a secondary task (Baddeley, 1986).

In the present experiment, the report of declarative knowledge by analogy learners ($M$ rules $= 3.07$) implies a degree of central executive activity during learning, possibly to implement the analogical instruction and/or monitor the success of the movement. However, because the analogy conveyed many of the technical rules incorporated in a topspin forehand implicitly, the role played by the central executive during motor acquisition may have been moderate. Subsequently, when the central executive was engaged in decision-making, motor performance of analogy learners, who had come to minimally depend on the central executive for movement control, was not disrupted.

Alternatively, Liao and Masters (2001) suggested that the analogy may not operate as a verbal instruction in working memory, but may instead be stored and manipulated as an image in the visuo-spatial sketchpad (Logie, 1995). Consequently, concurrent cognitive loads, such as high-complexity decisions, that primarily load the central executive (Jameson, Hinson, & Whitney, 2004), would fail to interfere with movement control dependent on the visuo-spatial sketchpad.

Future research may seek to verify the function (if any) of working memory in analogy learning. A task that loads the visuo-spatial sketchpad during motor performance may establish the extent of the visuo-spatial systems' involvement in the implementation of analogical instructions, whereas a suitably taxing decision that totally engages the capacity of the central executive should affect analogy learners if significant processing by the central executive is required for movement control.

A different explanation for the success of the Analogy condition in the present experiment may be that participants adopted a task-switching strategy, selectively switching attention from the decision to the motor response. However, for task switching to be an effective strategy, the time period between tasks must be sufficient to allow successful processing of the decision, prior to processing of the movement. In the present experiment, the frequency of ball service (30 balls/min) and the time between ball release and ball strike (approximately 450 ms) are likely to have enforced temporal constraints that prevented task switching. Furthermore, this argument does not account for the relative differences between the Analogy and Explicit condition when processing high-complexity decisions, as both conditions had the opportunity to adopt such a strategy.

The high-complexity decision designed for this experiment was intended to resemble decision-making strategies often used in sports; for example, baseball batters attend to the sequence of past pitches and the number of balls and strikes in order to predict the speed of the next pitch (Gray, 2002). However, it perhaps would have been more desirable to have used a decision-making task that was more specific to table tennis. Replication of this experiment with a more motor-task specific decision may further demonstrate the practical advantages of analogy learning.

In light of the benefits analogy learning has been shown to confer, future research should consider further the implications for sport performance, although the practical appeal would be enhanced if the advantages of analogy learning were shown to be durable over extensive retention periods. Currently, empirical evidence for the retention of implicitly acquired complex motor skills is limited to effects observed no more than 3 days after learning (Hardy et al., 1996; Masters, 1992; Maxwell et al., 2000). However, a recent experiment in our laboratory showed implicit motor learning advantages (robust motor performance under physiological stress) to be retained following a 1-year interval without rehearsal (Poolton, Masters, & Maxwell, 2005b).

Finally, an alternative approach to the decision/motor processing problem explored in this experiment would be to acquire the *decision* implicitly. Raab and Johnson (in press) argue that decision-making environments affect the balance of the contribution of implicit and explicit processes to decision learning. Future research should seek to develop learning environments that encourage implicit acquisition of complex decisions in an attempt to overcome performance disruptions associated with dual-task processing.

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