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Chapter 2

Explicit rules and direction of attention in learning and performing the table tennis forehand

Abstract

An experiment was conducted to examine the respective roles of explicit rules about movement execution and direction of attention in learning and performing a novel perceptual-motor task. To this end, four groups of learners (34 participants in total) acquired the table tennis forehand (450 repetitions) under different instructions (explicit, analogy, movement focus, and environment focus learning) and were subsequently tested under increased performance pressure and secondary task loading. In the absence of any differences in acquisition between the groups, the results revealed that the accumulation of a large number of explicit rules about task execution (i.e., explicit learning) was detrimental to performance under pressure and secondary task loading. It was therefore concluded that the number of explicit rules accumulated, rather than direction of attention during learning, determines the robustness of the acquired skill to performance pressure.

Introduction

At first blush, explicit rules about how to execute a movement, for example, as provided verbally by a coach, appear to play a crucial role in perceptual-motor learning. However, it has been demonstrated that explicit rules about movement execution are not essential, and that later performance is even more robust to increased performance pressure when a skill is learned implicitly, that is, without receiving or developing explicit rules about movement execution (Masters, 1992). Explicit skill learning would require involvement of working memory by testing movement-related hypotheses and integrating explicit rules into movement control (MacMahon & Masters, 2002; Masters & Maxwell, 2004). Once a skill is learned, explicit rules accumulated during acquisition may again be processed (reinvested) in working memory to interfere with proceduralized movement execution under demanding circumstances (e.g., under increased performance pressure). This line of reasoning is called the 'reinvestment' or 'conscious processing' hypothesis (Hardy, Mullen & Jones, 1996; Liao & Masters, 2001; Masters, 1992, 2000; Mullen, Hardy & Tattersall, 2005), and is sometimes also referred to as the 'explicit-monitoring theory' (Beilock & Carr, 2001; Pijpers, Oudejans, Holsheimer, & Bakker, 2003). Over the last decade empirical support for the conscious processing hypothesis of choking in the perceptual-motor domain has gradually accumulated (see Beilock & Carr, 2001; Lewis & Linder, 1997; Masters, 1992; Mullen & Hardy, 2000), although some deviant findings have been reported as well (e.g., Mullen et al., 2005).

Explicit learning is contrasted with implicit learning, which relies more on automatic and lower-level neural processes (Wulf & Prinz, 2001) with less involvement of working memory (Masters & Maxwell, 2004). Since little explicit knowledge is accumulated during implicit learning, this knowledge cannot be reinvested into movement control under pressure leaving automatic movement execution unaffected. As a result, implicitly learned skills are allegedly more robust to performance pressure. Thus far, studies on explicit versus implicit learning have emphasized the role of the number of explicit, verbalizable rules about movement execution that were accumulated in the learning process. However, explicit and implicit learning also differ in terms of direction of attention. Explicit learning not only results in the storage of verbally accessible, explicit rules about movement execution, it also directs attention towards movement execution itself, whereas in implicit learning explicit attention to movement execution is reduced or prevented. The aim of the present study was to examine the possibility that performance differences after explicit and implicit learning followed in fact from differences in attentional focus rather than from differences in the number of explicit rules accumulated.

Explicit rules and direction of attention

Wulf and colleagues have demonstrated repeatedly that direction of attention is an important factor in learning and subsequent performance. In particular, they have found consistent advantages of an external focus of attention (i.e., attention directed to the environment or the implement used, such as a wobble board or golf club) over an internal focus of attention (i.e., attention directed to the body parts involved in the movement, such as, feet in balancing on a wobble board or hands in golf putting) in learning and performing perceptual-motor tasks (Wulf, Lauerbach, & Toole, 1999; Wulf, Höß, & Prinz, 1998; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000; see Wulf & Prinz, 2001 for an overview). Note however that when operationalized in this manner an internal focus of attention is not identical to paying attention to specific rules or instructions about how to execute the movements in question, as in explicit learning. Beilock, Carr, MacMahon, and Starkes (2002) and Gray (2004) investigated the effects on performance of paying explicit attention to movement execution and demonstrated in golf putting, soccer dribbling, and baseball batting alike that such an internal focus of attention harms expert performance in a similar manner as the reinvestment of explicit rules would do under pressure. Liao and Masters (2002) also found that learning basketball free throw shooting with attention to movement execution resulted in performance decrements under stress. Collectively, these results indicate that attention to movement execution, which is also induced in explicit learning, may indeed lead to performance degradation under pressure.

While explicit learning implies by definition that attention is focused on movement execution, the relation between instruction and attention in implicit learning is less obvious. In classic implicit learning research explicit knowledge build up is prevented by concurrent execution of a secondary task, diverting attention away from movement execution itself. Although dual-task learning resulted in robust performance under increased pressure, the task-irrelevant attention caused structural performance degradation, rendering it impractical in real life settings. Recently, analogy learning has been identified as a more practical form of implicit learning (Liao & Masters, 2001). In analogy learning the essence of a complex movement is captured by a single metaphor that is used as instruction, effectively reducing the number of explicit rules about movement execution to a single global rule (Masters, 2000). In the present study, we adopted the experimental task and the implicit learning instruction from Liao and Masters (2001), who used the analogy of a right-angled triangle to facilitate the acquisition of the table tennis forehand. In particular, they instructed participants to pretend to draw a right-angled triangle in the air and to hit the ball while drawing the hypotenuse. By monitoring only this simple analogy, the load on working memory during learning is low, and participants are free to focus attention on other

important aspects of performance, such as environmental factors like the trajectory of the ball. As both the dual-task approach of implicit learning and analogy learning result in greater robustness to performance pressure, this would mean that a possible confounding role of attention must reside primarily in focussing on external or environmental cues, be they relevant for task execution or not, rather than on movement itself.

Recently, Poolton, Maxwell, Masters, and Raab (2006) and Maxwell and Masters (2002) already investigated the relation between focus of attention and knowledge accumulation. Maxwell and Masters (2002) did not find any relation between the direction of attention and the number of explicit rules accumulated. However, they could not rule out the possibility that participants in the internal focus groups had also adopted an external focus during task execution, making it difficult to draw firm conclusions. Poolton et al. (2006) examined whether performance differences following internal and external focus learning, as found by Wulf and colleagues (Wulf et al., 1998, 1999, 2000), were accompanied by differences in the number of explicit rules accumulated during skill acquisition. They distinguished between internal rules (i.e., rules concerning body parts involved, such as feet or knees) and external rules (i.e., rules concerning the environment or the implement used, such as a wobble board or golf club). Based on their results, Poolton et al. (2006) concluded that the number and not the direction (internal or external) of explicit rules determines performance deterioration under secondary task loading. However, following Wulf et al. (1998) they categorized attention to the implement (e.g., the golf club) as external. For example, "move the club back a short distance" was the external rule contrasting the internal rule "move your hands back a short distance" (p. 94, Table 2.1). Although, strictly speaking, those rules do imply a different focus of attention, it is doubtful whether the internal and external rules as defined by Poolton et al. (2006) also require a different involvement of working memory in terms of testing movement-related hypotheses and integrating them into movement control. As recognized by Poolton et al., it could well have been that differences were minimal in this regard, which would provide an alternative explanation for their finding that performance did not differ under secondary task loading between groups provided with internal and external rules, respectively.

The objective of the present study was to examine the respective roles of explicit rules and focus of attention by comparing learning performances under four different instructions aimed at inducing implicit learning, explicit learning, movement focus learning and environment focus learning, respectively. As for the comparison between implicit and explicit learning, we replicated the table tennis study by Liao and Masters (2001). In their study participants acquired the table

tennis forehand either with an analogy (implicit learning) or with a set of explicit rules (explicit learning). Our operationalization of the two attentional focus conditions was based on the alleged direction of attention induced during explicit and implicit learning as described in the preceding. Like the explicit instructions, the movement focus instructions directed attention to movement execution, in particular to important components such as wrist, elbow and shoulder movements. The environment focus instructions in contrast directed attention to relevant aspects of the environment, in particular the trajectory of the ball. This choice was motivated by the finding of Wulf et al. (2000) that focusing attention specifically on the effects of the movement (i.e., the ball trajectory after impact) was beneficial for learning the tennis forehand. Therefore, our environment focus instructions directed attention to the entire ball trajectory, that is, from ejection out of the ball machine to hitting the ball as well as from hitting the ball to its landing around the target.

By incorporating both implicit/explicit learning and movement/environment focus learning into a single experimental design, we could examine the relative weight of the presence of explicit rules on the one hand and the direction of attention on the other hand during both learning and performance. To this aim, we used written reports to determine the number and direction of accumulated explicit rules and included a low-pressure, a high-pressure and a dual-task test as part of the post-test examination to test the robustness of task performance after training. From the theoretical considerations advanced in the preceding at least three possibilities may be distilled. A first possibility is that different foci of attention may lead to differences in the number of explicit rules acquired. If this is the case, movement focus and explicit learning will lead to a larger number of reinvestable rules than both implicit and environment focus learning accompanied by a greater susceptibility to performance pressure. Movement and environment focus learning could then be considered forms of explicit and implicit learning, respectively. A second possibility is that direction of attention is subordinate to the number of explicit rules in performance decrements under pressure. In this case, the number of reinvestable rules will dictate whether performance would deteriorate under pressure irrespective of differences in direction of attention. A third possibility is that direction of attention during learning rather than the number of reinvestable rules is crucial in performance decrements under demanding circumstances. It this case, direction of attention will dictate performance degradation under pressure irrespective of differences in the number of internal rules accumulated. Given the inconclusiveness of the literature to date and the exploratory nature of this study concerning these outcomes, we had no a priori expectations as regards the likelihood of those three possibilities.

Method

Participants

Forty-two individuals (11 men, 31 women), between 17 and 30 years of age (mean = 21.8, *SD* = 3.58), participated in the experiment after having given their written informed consent. The participants had little or no experience in table tennis; eight participants (four men, four women) were able to hit the smallest targets repeatedly during the pre-test and were therefore excluded from further participation, leaving a total of 34 participants.

Experimental set-up

A table tennis robot (SITCO R-II-S TT ROBOT) was positioned behind a table tennis table (Tiga, mega CS) at the side of the table opposite to that of the participant. The robot fired balls at a rate of about 25 balls min^{-1}. The balls were launched with such a velocity and angle that they landed about 53 cm from the net at the participant's side of the table. A piece of black tape was attached to the table indicating where the ball would land approximately. The robot's launching precision was such that about 95% of the balls landed in a +10 cm to -10 cm range around the black tape. The target consisted of three concentric circles, with diameters of 9.5, 20.0 and 30.5 cm, respectively, at the opposite side of the table. A VHS-camcorder (Panasonic NV-M50) registered the landing position of the ball. The participants could see this camera but were not distracted by its presence as it was facing the table. Another camera (XM-1 DV camcorder) was placed behind the participant and fully covered the experimental set-up, in particular the movement of the participant. In the high-pressure test (see Design and Procedure) this camera was repositioned directly in front of the participant to increase perceived self-awareness. A table tennis bat from the Donic-700 series was used.

Task

Participants stood opposite the ball machine and were instructed to hit the ball diagonally across the table to the target at the opposite side of the table.

Design and Procedure

A pretest-posttest design was used. Prior to the pre-test (PT), the participants performed 15 practice trials (lasting about 35 s) to get used to the experimental set-up. The PT consisted of 50 trials under the sole instruction to hit the target as accurately as possible. The PT was followed by the acquisition phase, consisting of nine blocks of 50 trials each with a 10-minute break after the fifth block. The acquisition phase was followed by the post-test phase, consisting of three different

tests: a low-pressure test (LPT), a high-pressure test (HPT) and a dual-task test (DTT), each consisting of 50 trials as well.

Participants were assigned randomly to one of four groups: Explicit Learning (EL), Analogy Learning (AL), Environmental Focus learning (EF) and Movement Focus learning (MF). The EL group received an explicit set of instructions, which were drawn and translated from a guidebook (Hodges, 1993) and subsequently checked by an experienced coach, about how to execute the table tennis forehand (see Appendix A). The AL group received only a single instruction in the form of an analogy. Participants were instructed to pretend drawing a right-angled triangle with the bat. They were instructed to move the bat backwards over the bottom of the triangle and to hit the ball while moving the bat upward along the hypotenuse (cf. Liao & Masters, 2001).

The EF group was instructed to attend to the ball at all times, that is, from its ejection out of the ball machine to the bounce around the black tape until actual bat-ball contact and its subsequent trajectory to the target. Participants were instructed specifically to attend to the bounce on the table (near the tape) as well as the landing position of the ball after hitting it. The MF group received instructions to specifically focus on movement execution. To stimulate participants to focus on movement execution they were informed that they would have to answer one question about specific aspects of movement execution after each training block. Eventually, and because the number of sensible questions is limited, such a question was asked after five of the nine training blocks (i.e., training blocks 2, 3, 4, 6 and 8). In particular, the following five questions were asked:
-   Where did the swinging movement of your arm end?
-   Did you move your trunk during the stroke? If so, how?
-   At what moment during your stroke did you hit the ball?
-   How did the angle of your elbow vary during the stroke?
-   Did you move your feet during the stroke?

Answers were not recorded as it was expected that the anticipation of a question would already urge participants to direct attention to movement execution. Instructions for each group were repeated before each block.

Post-test

Following a similar procedure as Beilock and Carr (2001), the participants were informed after the ninth block that the upcoming block was their tenth and last block of training. No additional information or instructions were given. This block was the low-pressure test (LPT). The high-pressure test (HPT) was conducted after the LPT. To increase pressure in the HPT the participants were told that the next block was intended to determine how well the participants had learned their table

tennis forehand and that they could win a prize if they realized a certain target score. The target score was set at the estimated score of the LPT, which was determined by one of the experimenters who secretly kept score during the LPT (see Data Reduction). During the HPT scores were counted out loud by the experimenter in an attempt to increase pressure even further. In addition, a camera was placed conspicuously in front of the participant to further increase self-awareness. The participants performed the dual-task test (DTT) after the HPT. We decided not to counterbalance the tests in view of the delicacy of the pressure manipulation. Conducting the DTT before the pressure test could have had a detrimental effect on the pressure manipulation. During the DTT participants were instructed to keep on counting backwards from 1100 in steps of 3 while still performing the table tennis forehand. They were instructed to avoid mistakes in counting.

Data reduction

Dependent variables were: (i) experienced performance pressure, (ii) number of explicit rules acquired as well as their direction (movement related [internal] rules and environment related [external] rules), and (iii) actual performance. These variables were measured and operationalized as follows.

Performance pressure was measured using an anxiety thermometer in the form of a visual-analogue scale ranging from 0 ('not nervous at all') to 10 ('very nervous'). The anxiety thermometer, which was validated by Houtman and Bakker (1987), was applied directly after the LPT and HPT. Participants were asked how anxious they had felt during the test. To examine whether performance pressure increased from LPT to HPT analyses of variance (ANOVA) with repeated measures on the various test conditions were performed.

To assess the number of explicit rules, participants were asked to write down a detailed description of how they had executed the forehand stroke both after the warm-up trials (i.e., prior to any instruction; pre-test assessment) and upon completion of all post-tests (post-test assessment), which allowed us to determine not just the number of rules at the end of the experiment but also the number of rules actually acquired (these are usually not determined, which is a shortcoming in the literature, see Bennett, 2000). For the purpose of analyzing the written reports an inventory was made of all possible aspects of movement execution, which were then categorized as either being related to the environment (external) or to the movement itself (internal). In doing so, we distinguished between reinvestable rules (internal, e.g., "I keep my wrist firm"), and task but not movement related rules (external, e.g., "I look at the target"). Furthermore, when participants referred to a single rule about movement execution in two or more ways within their verbal reports (which was seldom the case), only one rule was scored. Two independent

observers scored the number and categorization of the explicit rules. As a reliable measure of inter-rater reliability we computed percentages error between the scores of the two observers (see Hughes & Franks, 2004). Those were 2.3% for the total number of rules and 0% for the categorization indicating high inter-rater reliability. Subsequently, the average scores of the two observers were analysed using repeated measures ANOVAs.

To exclude the possibility that differences in performance scores between groups in the DTT were the result of differences in performance on the secondary task, one-way ANOVAs were conducted on the percentage of correct responses and the average response time on the secondary task (obtained from video), respectively.

Actual table tennis performance was operationalized as the combined score of accuracy and movement execution. A similar performance measure as the one used by Liao and Masters (2001) was used based on the accuracy of the shots. The real-time counting during testing (as described in the preceding) was just done as a means to manipulate anxiety and was not considered reliable enough for further analysis. Therefore, accuracy was determined from the video recordings that covered the landing position of the ball. When the ball landed in the smallest circle four points were awarded; hitting the middle circle yielded three points and hitting the largest circle two points. Returning and placing the ball on the table at the opposite side of the net without hitting one of the targets gained the participants one point.

The quality of movement execution was quantified with scores ranging from 0 to 3 on the basis of the video recordings. The scores were operationalized as follows: a score of 0 meant no proper forehand execution at all; a score of 1 meant executing a forehand with a rigid trunk and without a follow-through (swinging the arm further after hitting the ball) longer than approximately 15-20 cm; a score of 2 meant executing a forehand with a follow through larger than 15 cm, but still no full swing (rigid trunk); a score of 3 meant a full swing of the arm and rotation of the trunk. The scoring system was established after consultation with a table tennis expert. Two independent observers scored a selection of 75 movements (5 trials of each of 3 post-tests of 5 participants). Because these were not just frequency counts percentage error could not be computed. Instead we determined the percentage inter-observer agreement, which was 95%.

Specific repeated measures ANOVAs were employed to test for performance differences between the different tests. Learning effects were examined by comparing scores on PT and LPT and performance pressure effects were examined by comparing scores on LPT and HPT, while the effects of secondary task loading were tested by comparing LPT and DTT.

For all ANOVAs effect sizes were calculated using Cohen's f statistic (Cohen, 1988). By convention, a Cohen's f of .10 represents a small effect, an f of .25 a medium effect and an f of .40 a large effect.

Results

Perceived pressure

To examine whether the pressure manipulation was successful, a Group (EL, AL, EF, MF) × Test (LPT, HPT) repeated measures ANOVA was performed on the subjectively perceived anxiety scores. The test only revealed a significant effect of test ($F_{1, 30} = 34.32$, $p < .001$, $f = 1.06$). On average, HPT was experienced as more stressful ($M = 3.19$, $SD = 2.39$) than LPT ($M = 1.11$, $SD = 0.95$). Previous use of the anxiety thermometer in a study on wall climbing revealed that high on a climbing wall, when participants were very anxious, average anxiety scores varied from 2.7 to 6.5, with scores ranging from 2.0 to 3.1 on a low anxiety control condition (Pijpers, et al., 2003; Pijpers, Oudejans, & Bakker, 2005). Thus, compared to those scores, an average anxiety score of 3.19 in the HPT (and an increase of 2.1 compared to LPT) indicates a moderately high increase in the level of anxiety following our ego-stressor manipulation.

Number and direction of rules

Table 2.1 shows the number of internal and external rules as determined for the pre- and post-test assessments, respectively. To examine whether the different instructions led to differences in the accumulation of rules, a Group (EL, AL, EF, MF) × Test (pre, post) × Direction of Rules (internal, external) ANOVA with repeated measures on the latter two factors was performed on the number of rules. It demonstrated significant main effects of Test ($F_{1, 30} = 47.14$, $p < .001$, $f = 1.25$), Direction of Rules ($F_{1, 30} = 63.38$, $p < .001$, $f = 1.45$) and Group ($F_{3, 30} = 3.11$, $p < .05$, $f = 0.56$), as well as significant interactions between Group and Direction ($F_{3, 30} = 3.15$, $p < .05$, $f = 0.68$), Group and Test ($F_{3, 30} = 3.93$, $p < .05$, $f = 0.63$) and Group, Test and Direction ($F_{3, 30} = 3.90$, $p < .05$, $f = 0.63$), and a marginally significant Test × Direction interaction ($F_{1, 30} = 3.60$, $p = .067$, $f = 0.35$). As the three-way interaction is crucial for understanding these results (albeit difficult to grasp), we performed four separate one-way (Group: EL, AL, EF, MF) ANOVAs on the number of internal rules on the pre- and post-test, as well as on the number of external rules on the pre- and post-test. These ANOVAs revealed that there were no significant differences between the groups on the pre-test for internal rules ($F_{3, 30} = 0.27$, $p = $ ns) or external rules ($F_{3, 30} = 0.32$, $p = $ ns), indicating that all groups started with comparable (small) numbers of internal and external rules. However, significant differences were revealed on the post-test for both internal ($F_{3, 30} = 5.07$,

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$p < .01$) and external rules ($F_{3,\ 30} = 3.77$, $p < .05$). Tukey post-hoc analyses on the number of internal rules revealed that EL participants reported significantly more internal rules on the post-test than AL participants ($p < .01$), suggesting that explicit and implicit learning indeed occurred in these groups. Recall that we operationalized internal rules as those rules that might be reinvested into movement execution. The number of internal rules of the EF and MF groups were intermediate and neither significantly different from each other nor from the number of internal rules of the AL ($ps = .49$ and .60, respectively) and EL groups, although there was a marginally significant difference between EL and MF ($p = .064$; $p = .12$ for the difference between EL and EF). Tukey post-hoc analyses on the number of external rules during the post-test revealed that EF participants had accumulated more external rules than EL and MF participants ($ps < .05$), suggesting that the external focus manipulation had been successful.

In sum, the analyses of the internal rules indicated that our attempt to discriminate between explicit and analogy learning groups (EL and AL) had been successful. Furthermore, again judging by the number of internal rules, the EF and MF instructions did not seem to have led to clear-cut implicit or explicit learning. Finally, the finding that the EF groups had accumulated more external rules than the other groups suggested that the manipulation of the external attentional focus had also been successful.

Table 2.1. Averages ± standard deviations of the number and direction of explicit rules before the pre-test and after the post-test for the different groups.

group	before pre-test		after post-test	
	internal	external	internal	external
EL	3.11 ± 1.45	0.67 ± 1.00	6.78 ± 2.68	0.78 ± 0.67
AL	2.50 ± 1.77	0.63 ± 1.06	2.63 ± 1.30	1.38 ± 1.19
EF	2.88 ± 1.25	0.88 ± 0.83	4.25 ± 2.82	2.25 ± 1.28
MF	2.89 ± 1.27	0.44 ± 0.73	4.00 ± 1.87	0.89 ± 0.78

Performance scores

Acquisition. To test for learning effects, a Group (EL, AL, EF, MF) × Test (PT, LPT) ANOVA was performed on the performance scores with repeated measures on Test. It only yielded a significant effect of Test ($F_{1,\ 30} = 68.05$, $p < .001$, $f = 1.50$). The corresponding means (see Figure 2.1) indicated that all groups improved their performance equally during the acquisition phase.

Performing under pressure. To examine the effects of pressure on performance, a Group (EL, IL, EF, MF) × Test (LPT, HPT) ANOVA was performed with repeated measures on Test, which only yielded a significant interaction ($F_{3, 30} = 3.10$, $p < .05$, $f = 0.56$). Inspection of the corresponding means showed that the performance of the EL group appeared to decrease under pressure, while that of the AL group appeared to increase (see Figure 2.1). In contrast, pressure seemed to have had no effect on the performance of the EF and MF learners.

Dual-task performance. One-way ANOVAs for percentage of correct responses (between 96-98%) and average response time (from 2.46-2.87 s) of secondary task execution revealed no significant differences between the groups ($Fs < 1$; *ns*), implying that possible group differences in table tennis performance under secondary task loading emerged from differences in instruction rather than from differences in performance on the secondary task. To examine the effects of the secondary task on table tennis performance, a Group (EL, AL, EF, MF) × Test (LPT, DTT) ANOVA was performed, which only yielded a significant effect of Test ($F_{1, 30} = 4.74$, $p < .05$, $f = 0.40$). This suggested that the introduction of the secondary task had a detrimental effect on performance without any significant differences between the groups. That this suggestion should be viewed with caution is evident from Figure 2.1 in which it is evident that on average the performance of the analogy learning group did not deteriorate with the dual task. Moreover, although the interaction between Group and Test did not reach significance ($F_{3, 30} = 1.89$, $p = .15$), Cohen's $f = .43$ indicates a large effect, which supports the suggestion that in contrast to performance of the EL, EF, and MF, table tennis performance of the AL improved with the dual task.
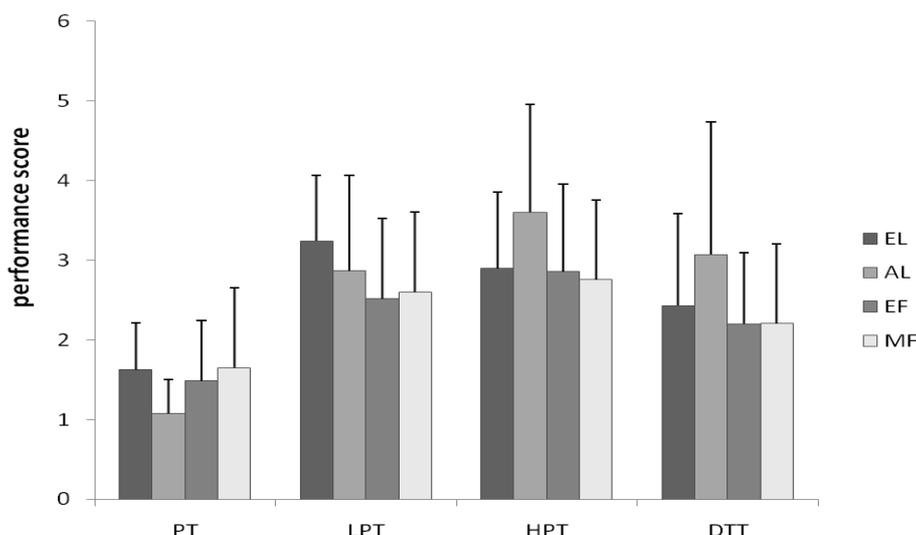

Figure 2.1. Averages ± standard deviations of the performance scores for the different groups for all tests.

Discussion

The aim of the present study was to compare the respective roles of explicit rules and direction of attention in perceptual-motor learning and subsequent performance. To this end, four groups of learners practiced the table tennis forehand under different sets of instructions corresponding to the learning modes of interest. After the acquisition phase the environment focus group reported more external rules than the movement focus and explicit learning groups, indicating that the manipulation of attentional focus had been successful. Furthermore, the results showed that the explicit learning group reported more internal rules than the implicit learning group after acquisition, implying that these manipulations were successful as well. These findings were supplemented with the observation that the explicit learning group was the only group to choke under pressure. All in all, it appears that the presence of explicit, reinvestable rules, rather than direction of attention, is detrimental to performance under pressure. In the remainder of this discussion, we will elaborate on the respective roles of explicit rules and direction of attention in learning and subsequent performance of a complex skill like the table tennis forehand.

Effects of the different instructions on rule formation

The formation of explicit rules was an important test criterion in the present study. In this context, a distinction was made between internal and external rules. Internal rules were defined as rules that can be reinvested in movement execution, whereas external rules were defined as rules that are related to the environment (and not reinvestable in movement execution). Although the environment focus group accumulated more external rules than the movement focus group, no differences were found between those groups in terms of skill acquisition, performance under pressure and dual-task performance, suggesting that the number of external rules accumulated was not an influential factor in table tennis performance.

It further appeared that the explicit learning group accumulated more internal rules than the implicit learning group, which is in accordance with the finding of Liao and Masters (2001) that providing elaborate instructions about movement leads to more reproducible rules about movement execution than a single analogy. It is conceivable that the learner repeatedly enacts the analogy given and is therefore less prone to develop new explicit rules for executing the movement in question.

Furthermore, the movement and environment focus groups reported an equal number of internal rules after learning. In comparison to the explicit and analogy learning groups there seemed to be a tendency towards more implicit rather than explicit learning, which was evident in the form of a marginally significant difference between the number of internal rules reported by the explicit learning group (6.8) and the movement focus group (4.0; $p = .064$). Particularly if the

number of internal rules reported prior to learning is taken into account, it is evident that with an environment or movement focus of attention participants accumulated hardly any additional internal (reinvestable) rules during learning (1.4 and 1.1 rules on average, respectively). It is striking that even the movement focus group did not accumulate more rules concerning movement execution. As regards this manipulation, our study can be compared to that of Liao and Masters (2002) where a movement focus learning group had accumulated five explicit, and thus reinvestable, rules after acquisition. Although it is unclear in the study of Liao and Masters how many rules were present prior to the acquisition phase, this might be an indication that our movement focus manipulation was not as successful as it could have been. On the other hand, Liao and Masters investigated basketball free throw shooting which is a self-paced task that might involve or lead to more rules than the externally paced table tennis forehand. Nevertheless, that we did not find greater rule accumulation in the movement focus group might also be in keeping with the recent distinction made by Jackson, Ashford and Norsworthy (2006) between explicit monitoring and reinvestment of conscious control. Those authors argue that despite a common emphasis on the similarities explicit monitoring does not necessarily have to imply more conscious control. Apparently, as far as we can judge from the number of internal rules found in the current study, just as with the analogy, learners with an attentional instruction exhibited no tendency to develop new explicit rules about movement execution.

Performance

Learning. We found no significant differences in learning progression across the experimental groups. Contrary to the idea of Prinz (1997) that actions are controlled best when attention is directed to the intended outcome instead of to the action itself, we found no differences in learning between our two attentional focus groups. Furthermore, previous findings of Wulf and colleagues (Wulf et al, 1998; Wulf et al., 1999; Shea & Wulf, 1999) showing superior learning of an external focus over an internal focus were not replicated with our environment and movement focus instructions. In general, only guiding attention towards either more environmental or more movement related cues seemed to have led to similar levels of performance progression as implicit or explicit learning.

The finding that learning progression was similar for explicit and implicit learning groups is consistent with the results of Liao and Masters (2001), who showed that learners do not necessarily require extensive instructions about movement execution. Apparently, an adequate analogy suffices. However, one should be reserved in generalizing those results to other complex perceptual-motor tasks. The triangle analogy describes the biomechanics of the forehand very

accurately. In other complex perceptual-motor tasks, finding a suitable metaphor could be more difficult.

Performing under pressure. Not only skill improvement as such is important in perceptual-motor learning, but also the robustness of the acquired skill to changing circumstances, such as increased performance pressure. We replicated earlier findings suggesting that implicitly learned skills are more robust to performance pressure than explicitly learned skills (Hardy et al., 1996; Liao & Masters, 2001; Masters, 1992, 2000). In fact, the performance of the analogy learning group seemed to improve from low to high pressure (see Figure 2.1). Similar performance improvements were also found in previous studies (e.g., Hardy et al, 1996; Liao & Masters, 2001; Masters, 1992) and can be explained by Eysenck and Calvo's (1992) processing efficiency theory, according to which the negative effects of anxiety may (initially) be compensated for by increased efforts in task execution. With increased motivational effort, performance can remain unhampered or even improve when anxiety increases. The results obtained for the high pressure test may be interpreted along those lines.

Furthermore, the group with the highest number of internal (reinvestable) rules after acquisition, the explicit learning group, was the only group to choke under pressure. This finding is consistent with Masters' idea that when pressure increases explicit rules are reinvested in working memory, thereby interfering with proceduralized movement execution (Liao & Masters, 2001; Masters, 1992, 2000; Masters & Maxwell, 2004). Despite clear differences in focus of attention, both attentional focus groups performed equally well in the pressure test, implying that direction of attention during acquisition is not a determining factor for performance degradation in pressure situations. In combination, these results suggested that the number of reinvestable, internal rules rather than direction of attention is crucial in performance under pressure. In their study on the relation between the accumulation of explicit rules and the predisposition to reinvest them under pressure, Poolton, Maxwell and Masters (2004) reached a similar conclusion.

Dual-task performance. Although the Group × Test interaction did not reach significance (perhaps due to a lack of statistical power), Figure 2.1 as well as Cohen's *f* suggests that the number of explicit rules may have played a role in performance differences under secondary task loading, because the explicit learners showed a drop in performance, whereas the analogy learners demonstrated an increase in performance (albeit that, strictly speaking, this difference was not significant). This would be in line with previous findings indicating that the number of explicit rules is an important factor in performance degradation under secondary

task load (Liao & Masters, 2001; Maxwell, Masters, Kerr & Weedon, 2001; Poolton et al., 2006). Masters and Maxwell (2004) argue that the amount of explicit knowledge indexes the dependence on working memory during learning. By adding a cognitive load, working memory dependence of explicitly learned skills would result in an overload of attentional capacity and, consequently, a degradation of performance. An alternative line of reasoning is that performance under secondary task loading can be used as an index of the degree of automatization, leading to the conclusion that in the current study all groups, except for the analogy learning group whose performance seemed automatized most, achieved comparable levels of automatization. By definition, automatized skills require little conscious control, allowing experts to sustain performance on a primary task when a secondary task is introduced.

In conclusion, after 450 repetitions the presence of explicit rules rather than the adopted direction of attention appears to be the dominant factor in the occurrence of performance degradation under pressure, without having a significant influence on learning progression or automatization. The question remains how the relation between the number of reinvestable rules and automatization evolves over longer learning periods.

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Appendix A

Explicit instructions for the execution of a right handed table tennis forehand drive used for the Explicit Learning group (adopted from Hodges, 1993):

Preparation phase:

Step 1: Stand in ready position

Step 2: Arm relaxed

Step 3: Bat slightly opened towards topspin

Step 4: Keep the wrist loose and cocked slightly down

Step 5: Left foot slightly before right

Back swing:

Step 1: Rotate body backwards at waist and hips

Step 2: Rotate right arm back at elbow

Step 3: Shift weight to the back foot

Forward swing:

Step 1: Rotate weight to front foot

Step 2: Rotate body forward on waist and hips

Step 3: Rotate right arm forward from the elbow

Step 4: The bal-bat contact is made in front and to the right side of the body

Follow through:

Step 1: Bat moves forward and slightly up naturally

Step 2: Return to ready position.