Automatization and deautomatization of perceptual-motor skills

Koedijker, J.M.

2010

Chapter 6

General discussion

General discussion

The experimental studies presented in this thesis all contribute to the understanding of the processes of automatization and deautomatization in the perceptual-motor domain. In particular, the present thesis addresses the influence of the type of instruction on skill acquisition and provides insight into the deautomatization of performance under different disruptive conditions. The first part of this epilogue discusses the findings of Chapters 2 and 3 in light of Masters' reinvestment hypothesis. Next, alternative theoretical frameworks (Processing Efficiency Theory and its successor, Attentional Control Theory) that possibly provide a more complete account of the results are considered. The second part of this thesis discusses the suggestion that skill automatization already develops relatively early in learning. This suggestion will be contrasted with traditional ideas proposing that automatization is the final step of skill acquisition (Anderson, 1982; Fitts & Posner, 1967) and will be further explored within the theoretical framework proposed by Bernstein (1996). Finally, the future direction of implicit learning is briefly discussed with the aim to derive theoretical and practical guidelines for instructions and future research.

Reinvestment hypothesis

One of the main objectives of this thesis was to test Masters' (1992, 2000) hypothesis that performance decrements under increased psychological pressure are caused by the involvement of task-relevant, explicit rules in the control of relatively automated motor processes (Liao & Masters, 2001; Masters, 1992, 2000; Masters & Maxwell, 2004). In Chapter 2 the explicitly instructed group reported the highest number of explicit rules after acquisition and was the only group to choke under pressure. This result is in accordance with earlier work showing that minimizing the accumulation of explicit rules about task execution during learning prevents performance disruption under increased pressure (Hardy, Mullen, & Jones, 1996; Liao & Masters, 2001; Masters, 1992, 2000) and thus Masters' reinvestment hypothesis of choking under pressure.

Chapter 2 shows that the explicit learners, in contrast to the analogy instructed participants, demonstrated a lapse in performance under secondary task loading. Apparently, accumulating a high number of explicit rules about movement execution is also detrimental to performance under secondary task loading (Liao & Masters, 2001; Maxwell, Masters, Kerr, & Weedon, 2001; Poolton, Maxwell, Masters, & Raab, 2006). Masters and Maxwell (2004) argued that working memory is involved in the process of testing task-related hypotheses and the accrual of numerous task-relevant rules, which are characteristic for explicit learning. Consequently, adding a cognitive load to explicitly learned skills would overload working memory capacity as both primary skill execution and the execution of the secondary task depend on, and compete for, the same working memory resources. In contrast, lower working memory demands of implicitly learned skills would allow for the simultaneous processing of both the primary motor task and the secondary cognitive task.

However, traditional accounts of skill learning (e.g., Bernstein, 1996; Fitts & Posner, 1967), which advocate the employment of explicit learning techniques during the first stage of learning, hold that only the first stage of learning is characterised by the utilization of working memory resources. After extensive practice, skill execution should lose its dependency on such attentional resources and attain the ability to run automatically. One way to measure skill automaticity is to determine the degree to which primary task performance can sustain the addition of a cognitive demanding secondary task. Therefore, performance stability under secondary task loading might reflect permanent differences in working memory dependence of skill execution (Masters & Maxwell, 2004), but it might also be indicative of how far skill execution has progressed on the skill acquisition continuum.

Kottke (1980) argued that minimally 10,000 repetitions of a complex perceptual-motor skill are needed to start to produce the first signs of truly automatic movement execution. Nearly all studies that have demonstrated robustness to performance pressure of implicitly learned skills over explicitly learned skills, including Chapter 2 of the present thesis, involved a maximum of 500 repetitions (e.g., Hardy et al., 1996; Koedijker, Oudejans & Beek, 2007; Liao & Masters, 2001; Masters, 1992 – see Maxwell et al., 2000 for an exception). It seems reasonable to argue that after only 500 repetitions explicit learners may still operate within one of the earlier stages of perceptual-motor learning before reaching automaticity. If explicit learners can still be considered novices after such short stints of practice, then their performance could (or would) be harmed by the introduction of an attention demanding secondary task as it has not yet become automatised (Passingham, 1996). As implicit learning techniques are used in passing the first cognitive stage, it is possible that differences in performance under secondary task loading between explicitly and implicitly learned skills are confounded by differences in skill automaticity rather than by structural differences in working memory dependence.

Furthermore, numerous studies that provided support for Masters' reinvestment explanation of choking under pressure – that is, advantages of implicitly learned skill over explicitly learned skill under increased performance pressure – might also be confounded by differences in skill automatization as they also report differences in performance under secondary task loading (Koedijker et al., 2007; Liao & Masters, 2001; Poolton, Masters & Maxwell, 2005; Poolton, Maxwell, et al., 2006). Therefore, in Chapter 3 we sought to test the effects of analogy and explicit learning on performing under pressure at higher levels of automaticity up to a total of 10,000 repetitions, that is, many more than the 500 repetitions that have been used in previous research. Performance of both analogy and explicit learners seemed to be robust to secondary task loading already after 1,400 repetitions, suggesting that both learning groups already reached a similar degree of automaticity after 1,400 repetitions. Interestingly, after 1,400 repetitions the high number of explicit rules reported by the explicit learners did not lead to performance degradation under pressure with similar effects of increased pressure on performance for both groups. This finding is not in line with the reinvestment hypothesis, as despite a relatively high number of explicit rules, performance of explicit learners did not decrease with increased anxiety. In fact, the performance of both groups seemed to improve from low to high pressure. As the manipulations employed in Chapters 2 and 3 can be considered representative for the vast majority of studies on this topic, the main point that can be distilled from Chapters 2 and 3 is that when explicit learners demonstrate signs of automatic performance, they appear to be respond equally well to performance pressure as implicitly learners.

Processing Efficiency and Attentional Control Theory

Eysenck and Calvo's (1992) processing efficiency theory might provide an alternative framework for interpreting the findings of Chapters 2 and 3. The processing efficiency theory has two basic premises. One is that increased performance pressure leads to worry and self-evaluation (Baumeister, 1984) and that these self-evaluation processes pre-empt working memory resources. One might argue on the basis of Chapters 2 and 3 that early in learning, when explicit rules about movement execution have not yet become proceduralised and still depend on working memory resources, the additional consumption of working memory resources by increased performance pressure causes an overload of working memory resources leading to performance degradation. Implicitly learned skills rely little on working memory resources from the start of acquisition and despite losing capacity to effects of performance pressure, resources are still sufficient to support movement execution.

The second premise of processing efficiency theory is that possible negative effects of anxiety may be compensated for by increased efforts in task execution. In most situations increased effort and motivation allow for optimal performance despite high incentives. For example, during the Olympics we witness, the enormous pressure notwithstanding, numerous world-class performances and only an occasional failure. Thus, increased effort can minimize the adverse effects of anxiety on performance. Although processing efficiency theory was originally claimed to be most relevant for cognitive task performance (Eysenck & Calvo, 1992), several recent studies have generated empirical support for the theory with respect to perceptual-motor tasks (Mullen, Hardy, & Tattersall, 2005; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Wilson, Smith, Chattington, Ford, & Marple-Horvat, 2006). Although processing efficiency theory provides a useful framework for interpreting the effects of anxiety on performance, some of the underlying theoretical assumptions were insufficiently precise (see Eysenck, Derakshan, Santos, & Calvo, 2007). In order to remedy this shortcoming, Eysenck et al. (2007) elaborated processing efficiency theory into attentional control theory. Both theories share the position that performance pressure distracts attention away from task-relevant to task-irrelevant information sources (see also Wine, 1971). Additionally, attentional control theory hypothesises that working memory is responsible for the efficient allocation of attention towards relevant information sources. According to attentional control theory, increased anxiety impairs functioning of the ‘shifting’ and ‘inhibition’ functions of working memory (Myake et al., 2000). The inhibition function inhibits attentional control from diverting away towards task-irrelevant stimuli, whereas the shifting function involves the allocation of attention on task-relevant stimuli. Impairment of inhibition and shifting functions have consequences for how attention is controlled under increased performance pressure.

Corbetta and Shulman (2002) argued that two different systems are responsible for the control of attention, the goal-directed attentional system and the stimulus-driven attentional system. The goal-directed attention system is mainly involved in preparing and modulating the selection of task-relevant stimuli. The stimulus-driven attention system, in contrast, involves the detection of salient stimuli, especially when such stimuli are unexpected and could prove relevant for self-preservation. Attentional control theory postulates that under increased performance pressure inhibiting and shifting functions of working memory fail to direct and maintain attention to task-relevant stimuli (under guidance of the goal-directed attentional control system), allowing the stimulus-driven attentional control system to take a more prominent role with salient or emerging task-irrelevant stimuli to use critical working memory resources, rather than sources more valuable for maintaining high performance.

A striking example of such a shift from goal-directed attentional control to stimulus-driven attentional control is visible when performing a shooting simulation drill (Nieuwenhuys & Oudejans, in press; Oudejans, 2008). Instead of directing attention to efficient aiming (i.e., goal-directed attention towards the target), control of attention may switch to threatening stimuli, that is, the gun and head of the opponent (i.e., stimulus-driven control of attention). Another example is when a novice driver is taking a driver's exam, he/she should maintain goal-directed attentional control with attention divided between the road, fellow road users and road signs and subsequently adapt speed and direction. However, stimulus-driven control diverts attention towards task-irrelevant stimuli, such as worries about consequences of failure, hereby possibly neglecting crucial information about speed, road signs or other road users.

So how can attentional control theory explain the results of Chapters 2 and 3? The pressure manipulations alone did not lead to performance loss of the implicit learners of Chapters 2 and 3 and the explicit learners of Chapter 3. Under these specific conditions, the allocation of extra effort allowed for high performance. However, the explicit learners in Chapter 2 still needed working memory resources to support movement execution and this, in combination with the pre-empting of resources as a consequence of increased pressure, led to impaired working memory function, as attention shifted away from task-relevant sources (such as the use of movement-related rules) towards distracting information sources.

All in all, the combined results of Chapters 2 and 3 are more supportive of an attentional control account rather than a conscious processing or reinvestment account of choking. It is tempting to draw parallels between choking under pressure and the deautomatization of well-learned movements under skill-focus (explicit monitoring) instructions and the lengthening of movement preparation time (see Chapter 4) as they both share an outcome similarity with choking under pressure – in both situations automated performance seems disrupted and deautomatized. However, this is no reason to assume that both share the same underlying mechanism.

Nevertheless, reinvestment theory and attentional control theory might be more alike than currently thought in the literature (see Wilson, Smith & Holmes, 2007). At first glance, both seem to predict different effects. Attentional control theory postulates that increased allocation of effort to task execution may compensate for the distracting effects of anxiety, whereas conscious processing theories predict that increased allocation of attentional resources leads to disruption of performance by shifting towards more effortful, non-automatic control processes. However, both theories do predict that under pressure a performer attempts to exploit alternative strategies to maintain task performance by increasing the allocation of attentional resources. The results from the externally-paced table tennis forehand return used in Chapters 2 and 3 indicate that resources are distributed more towards maintaining cognitive functioning. But one might raise the question whether the distribution of additional attentional resources under pressure are always directed towards maintaining cognitive functioning or that a different task, different levels of expertise or different cultural or personal dispositions would see a shift in the distribution of attention towards movement execution. Future research on the topic of choking under pressure should not focus on whether pressure leads to conscious processing or distracts from task execution, but should attempt to integrate these two views into a more comprehensive view on choking.

Movement automatization: Final or first step?

Traditional accounts of skill acquisition purport that the automatic or procedural stage is the final stage in motor learning (Anderson, 1992; Fitts & Posner, 1967). However, the results of Chapters 2 and 4 show that instruction by analogy almost immediately installs automaticity and that also explicitly instructed participants seemed to have reached automaticity already after a 'mere' 1,400 table tennis forehand repetitions. These results are consistent with Bernstein's (1996) notion that attaining automaticity is only one of the first steps in achieving expertise (dexterity), followed by the parallel processes of standardization and stabilization. Standardization of movement involves the fine-tuning of skill execution to a high level of accuracy and consistency. Stabilization of movement automaticity is the process of acquiring resistance of performance to changing environmental demands. Although the analogy instruction in the present study appeared to circumvent the declarative stage of learning and almost instantaneously installed automatic skill execution, the disrupted performance displayed by the analogy learners in the speeded condition suggests that their movements were not stable enough to cope with the disruptive influence of increased temporal demands.

Keele, Jennings, Jones, Caulton, and Cohen (1995) proposed two hierarchically organized learning systems developing independently and at different rates. One system specifies the structure of movement (the order of subsequences) and is represented at an abstract, explicit level, whereas the other system represents the generation of the actual forces involved in movement production (effector dynamics; Hikosaka, et al., 1999; Rosenbaum, 1990; Wilde & Shea, 2006) and is considered implicit in nature. Within these two systems, the cognitive representation of the sequence structure is believed to develop at a quicker rate than the effector-dependent movement dynamics. For analogy learners the sequence structure might be established very early in learning as there is only one rule – the analogy – to integrate into movement execution, thus making the use of working memory processes to establish the structure obsolete almost from the beginning of learning. The multitude of information provided for or accumulated by explicit learners will take longer to establish and thus needs working memory resources early in learning. With the establishment of the movement structure the first signs of automaticity become visible (i.e., stable performance under secondary task loading), but the motor system needs more time and practice to stabilise and standardise the movement dynamics.

In Chapter 5 we observed similar phenomena. The representation of the movement structure, that is, how the different elements of the sequence are linked together, also seems to become established early in learning. Experiment 2 of Chapter 5 shows that interference effects are visible already after 50 repetitions of initial learning. Additional repetitions did not seem to magnify the interference between similar movement sequences, suggesting that the representation of the movement structure was already established after 50 repetitions and responsible for the occurrence of movement-specific interference effects. Apparently, the positive effects of establishing the movement structure, that is, freeing the necessary working memory resources for further skill refinement, also brings about the unwanted interference effects visible in Chapter 5.

It seems that after establishing the underlying structure of a movement, increased practice is primarily aimed at improving the dynamics of movement execution in search of movement dexterity, acquiring characteristics such as increased accuracy and the ability to cope with high temporal or other demands (see Chapter 4). This also points to practical implications for how skills are taught by practitioners. If it only takes a relatively short period before to establish the movement structure and to acquire the first signs of automaticity, and to learn the effects that might accompany this, teachers must be very careful about how they instruct participants from the very start of learning. Providing an analogy almost immediately establishes the movement structure and installs automatic execution, but it might result in difficulties to change the execution of the analogy when necessary (see also Beek, 2000; Bennett, 2000). Evidently, studying the effects of analogy learning over longer periods of learning (well into the phases of stabilisation and standardisation) is a direction for future research.

Future direction of implicit learning

The evidence provided in Chapters 2 and 3 is not entirely supportive of the hypothesis that the combination of the presence of explicit rules and increased performance pressure leads to a reinvestment of conscious control. The results of Chapter 3 suggest that after longer periods of learning, this explicit knowledge about how to perform is not harmful anymore in demanding situations and might even be beneficial in reaching elite levels of performance. This, however, should not be taken to imply that implicit learning techniques should be discarded altogether. As demonstrated in Chapters 2 and 4, providing an efficient analogy immediately results in lower working memory demands of performance compared to traditional rule-based learning. Obviously, this holds advantages for motivation, processing additional information, and tactical decision making (Masters, Poolton, Maxwell, & Raab, 2008; Poolton, Masters, Maxwell, & Raab, 2006). Furthermore, analogy instructions might also prove to be beneficial for performance in light of other cognitive or physiological modalities, such as physiological fatigue (Poolton, Masters, & Maxwell, 2007), although the analogy instruction failed to provide an immediate solution to increased temporal demands. In sum, analogy learning might not be a solution to minimize the occurrence of choking under pressure in expert performance; it does have several other potential merits in skill acquisition and therefore warrants further research and development, not only within the realm of expert performance in sports, but also in other relevant domains such as surgery (Masters, Lo, Maxwell, & Patil, 2008), geriatrics (Wong, Masters, Maxwell, & Abernethy, 2009), and rehabilitation (Orrell, Eves, & Masters, 2006).

References

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89*, 369-406.

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects on incentives on skillful performance. *Journal of Personality and Social Psychology, 46,* 610-620.

Beek, P. J. (2000). Toward a theory of implicit learning in the perceptual-motor domain. *International Journal of Sport Psychology*, *31*, 547-554.

Bennett, S. J. (2000). Implicit learning: Should it be used in practice? *International Journal of Sport Psychology*, *31*, 542-546.

Bernstein, N. (1967). *The coordination and regulation of movements*. New York, NY: Pergamon.

Corbetta M., & Shulman G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience,3*, 201-215.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion, 6,* 409-434.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*, 336-353.

Fitts, P., & Posner, M. (1967). *Human performance*. Belmont, CA: Brooks-Cole.

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

Hikosaka, O., Nakahara, H., Rand, M. K., Sakai, K., Lu, X., Nakamura, K., Miyachi, S., & Doya, K. (1999). Parallel neural networks for learning sequential procedures. *Trends in Neuroscience, 22*, 464-471.

Keele, S. W., Jennings, P., Jones, S., Caulton, D., & Cohen, A. (1995). On the modularity of sequence representation. *Journsal of Motor Behavior, 27,* 17-30.

Koedijker, J. M., Oudejans, R. R. D, & Beek, P. J (2007). Explicit rules and direction of attention in learning and performing the table tennis forehand. *International Journal of Sport Psychology, 38,* 227-244.

Kottke, F. J. (1980). From reflex to skill: The training of coordination. *Archives of Physical Medicine and Rehabilitation, 61*, 551-561.

Liao, C.-H., & Masters, R. S. W. (2001). Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences*, *19*, 307-319.

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

Masters, R. S. W. (2000). Theoretical aspects of implicit learning in sports. *International Journal of Sport Psychology*, *31*, 530-541.

Masters, R. S. W., Lo, C. Y., Maxwell, J. P., & Patil, N. G. (2008). Implicit motor learning in surgery: Implications for multi-tasking. *Surgery, 143,* 140-145.

Masters, R. S. W., & Maxwell, J. P. (2004). Implicit motor learning, reinvestment and movement disruption. What you don't know won't hurt you? In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research, theory and practice* (pp. 207-228). London: Routledge.

Masters, R. S. W., Poolton, J. M., Maxwell, J. P., & Raab, M. (2008). Implicit motor learning and complex decision making in time-constrained environments**,** *Journal of Motor Behavior, 40,* 71-79

Myake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H, Howerter, A., & Wager, T. D. (2000). The university and diversity if executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

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

Maxwell, J. P., Masters, R. S. W., Kerr, E., & Weedon, E. (2001). The implicit benefit of learning without errors. *The Quarterly Journal of Experimental Psychology, 54A,* 1049-1068.

Mullen, R., Hardy, L., & Tattersall, A. (2005). The effects of anxiety on motor performance: A test of the conscious processing hypothesis. *Journal of Sport & Exercise Psychology, 27*, 212-225.

Nieuwenhuys, A., & Oudejans, R.R.D. (in press). Effects of anxiety on handgun shooting behavior of police officers: A pilot study. *Anxiety, Stress, & Coping, 23*, 225-233. **DOI:** 10.1080/10615800902977494

Nieuwenhuys, A., Pijpers, J.R., Oudejans, R.R.D., Bakker, F.C. (2008). The influence of anxiety on visual attention in climbing. *Journal of Sport and Exercise Psychology, 30*, 171-185.

Orrell, A. J., Eves F. F., & Masters, R. S. W. (2006). Motor learning of a dynamic balancing task after stroke: Implicit implications for stroke rehabilitation. *Physical Therapy, 86,* 269-380.

Oudejans, R.R.D. (2008). Reality based practice under pressure improves handgun shooting performance of police officers. *Ergonomics*, *51*, 261-273

Passingham, R. E. (1996). Attention to action. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 1473-1479.

Poolton, J. M., Masters, R. S.W., & Maxwell, J. P. (2005). The relationship between initial errorless learning conditions and subsequent performance. *Human Movement Science, 24*, 362-378.

Poolton, J. M., Maxwell, J. P., Masters, R. S. W., & Raab, M. (2006). Benefits of an external focus of attention: Common coding or conscious processing? *Journal of Sports Sciences*, *24*, 89-99.

Poolton, J. M., Masters, R. S. W., & Maxwell, J. P. (2007). Passing thoughts on the evolutionary stability of implicit motor behaviour: Performance retention under physiological fatigue. *Consciousness & Cognition, 16*, 456-468.

Rosenbaum, D. A. (1990). On choosing between movement sequences: Comments on Rose (1988). *Journal of Experimental Psychology: Human Perception and Performance, 16,* 439-444.

Wilde, H., & Shea, C. H. (2006). Proportional and non-proportional transfer of movement sequences. *Quarterly Journal of Experimental Psychology, 59,* 1626-1647.

Wilson, M., Smith, N. C., Chattington, M., Ford, M., & Marple-Horvat, D. E. (2006). The role of effort in moderating the anxiety-performance relationship: Testing the prediction of processing efficiency theory in simulated rally driving. *Journal of Sports Sciences, 24,* 1223-1233.

Wilson, M., Smith, N. C. & Holmes, P. S. (2007). The role of effort in influencing the effect of anxiety on performance: Testing the conflicting predictions of processing efficiency theory and the conscious processing hypothesis. *British Journal of Psychology, 98,* 411-428

Wine, J. (1971). Text anxiety and direction of attention. *Psychological Bulletin, 76*, 92-104.

Wong W-L., Masters, R. S. W., Maxwell, J. P., & Abernethy, B. (2009). The role of reinvestment in walking and falling in community-dwelling older adults. *Journal of the American Geriatrics Society, 57*, 920-922.