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Implicit and Explicit Processes in Motor Learning and Performance

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Abstract

Knowledge can be acquired through either an explicit or implicit learning process. Knowledge produced by an explicit learning process is explicit and can be verbalized; on the other hand, knowledge accumulated by way of an implicit learning process is implicit and difficult to be articulated. The distinctive characteristics of these two processes have attracted attention in psychology domain. In motor behavior domain, several researchers, though not many, have examined implicit process in motor learning and performance. This paper, through literature review, examines the roles of implicit and explicit processes in motor learning and discussed several methods proposed to teach motor skills through implicit process. Factors related to the implicit and explicit nature of learning processes, e.g., explicit instructions given to learners in practice and level of self-focused attention induced by psychological stress in performance, are also discussed.

Key words: implicit process, explicit process, implicit learning, verbal instruction, self-focused attention

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Implicit Learning

Issues related to implicit learning have attracted the attention of researchers for the past three decades (see Berry, 1996; Reber, 1967; Reber, 1993; Reed & Johnson, 1998). Implicit learning is described as a process in which an individual "learns about the structure of a fairly complex stimulus environment, without necessarily intending to do so, and in such a way that the resulting knowledge is difficult to express" (Berry, 1996, p. 203). Reber (1989) defined implicit learning as an unconscious process and the knowledge produced by the process as tacit and abstract (p. 219).

Hayes and Broadbent (1988) describe learning processes that produce either explicit or implicit knowledge with a more functional approach and defined them as selective or unselective modes of learning, respectively. They proposed that a selective mode of learning, which is analogous to explicit learning, involves active hypothesis testing and information collecting activities in working memory to generate associations between variables; resulting in explicit knowledge. An unselective mode of learning, which is analogous to implicit learning, involves passive aggregation of frequency information about the environment and results in implicit knowledge.

Hayes and Broadbent (1988) also indicated that explicit learning requires resources in working memory for forming associations and cognitive structures, while implicit learning does not require such resources, due to the automatic nature of accumulation of frequency information. Working memory is a hypothetical, abstract mechanism in the memory system in which information, either retrieved from long-term memory or temporally picked up from the environment, is manipulated and processed (Baddeley, 1990; Baddeley & Hitch, 1974). Working memory consists of three major components: a central executive, a phonological loop, and a visuo-spatial sketchpad. The central executive is an attentional controller which supervises and coordinates the other two components. The phonological loop is involved in processing verbal-based information, and the visuo-spatial sketchpad is responsible for manipulating visual images. According to Baddeley (Baddeley, 1990; Baddeley & Hitch, 1974), the capacity of these components of working memory is limited and only a small amount of information can be manipulated in working memory at one time. Based on the concept of working memory, Hayes and Broadbent (1988) proposed that a concurrent secondary task load would affect explicit learning but not implicit learning. They argued that in an explicit process working memory would be overloaded from manipulating both explicit knowledge and the secondary task at the same time. Implicit learning, on the other hand, does not involve manipulation of explicit knowledge and frees working memory for performance of the secondary task.

Hayes and Broadbent (1988) provided support for this by showing that in a complex task reaction times of explicit, but not implicit learners, were increased by a concurrent secondary task (random letter generation - Baddeley, 1966).

Evidence regarding implicit learning processes has come from a variety of domains, including artificial grammar learning (e.g., Reber 1967; Reber, Walkenfeld, & Hernstadt, 1991; Turner & Fischler, 1993), sequence learning (e.g., Curran & Keele, 1993; Keele & Jennings, 1992; Stadler, 1995), control of computer-simulated dynamic systems (e.g., Berry, 1991; Berry & Broadbent, 1984; Hayes & Broadbent, 1988), and probability learning (e.g., Reber, 1989; Reber & Millward, 1968). Implicit learning has been generally characterized as a process producing knowledge that is not easy to articulate (Berry, 1996; Reber, 1993) and that learners are not aware of (lack of metaknowledge, Chan, 1992). In addition, implicitly learned tasks have been shown to be more resilient under a concurrent secondary task load (Dienes & Berry, 1997; Hayes & Broadbent, 1988) and under psychological stress (Reber, 1993).

Despite of the weight of evidence regarding implicit learning, some researchers claimed that no convincing evidence supporting implicit learning exists and all learning processes are explicit. Shanks and St. John (1994), for example, argued that all knowledge is available to consciousness in some form thus no learning process can be considered as implicit. They proposed that tests of implicit learning should satisfy both the Information and Sensitivity Criteria. That is, the tests must examine the exactly knowledge responsible for performance changes and the tests must be sensitive to all the relevant explicit knowledge. Shanks and St. John (1994), based on their review of implicit learning, concluded that there had been no satisfactory demonstration of unconscious learning. Shanks and St. John’s (1994) ‘unconsciousness’ criterion of implicit learning has been criticized as inappropriate due to the possible interactions between explicit and implicit learning processes (Berry, 1994; Dienes & Perner, 1994; Reber & Winter, 1994). Besides, as indicated by Dienes and Berry (1997), the more sensitive the test used to tap explicit knowledge, the more likely that the test will actually elicit implicit knowledge. In this paper, characteristics commonly found in implicit learning studies, i.e., knowledge acquired is not easy to articulate and learners are lack of metaknowledge, are used as the criteria to examine implicit learning.

Implicit Motor Learning

There are, however, relatively few studies which have examined implicit motor learning. Implicit motor learning refers to the acquisition of a motor skill without the acquisition of explicit knowledge of how to carry it out. Several authors have emphasized the salience of implicit processes in motor skill learning. Wulf and

Schmidt (1997) suggested that implicit learning may be particularly relevant in the acquisition of motor skills, given the automatic nature of skilful motor performance. Magill (1998) pointed out that knowledge of the ‘regulatory features’ of a motor skill can be learned and are likely to be learned more effectively through implicit processes. The regulatory features refer to the information in environmental contexts concerning how the body and limbs should act to carry out a successful performance (Gentile, 1987). McLeod and Dienes (1993) also indicated that successful performance of a motor skill (e.g., catching a cricket ball) relies on unconscious problem solving abilities when reacting to the changing stimulus environment. Finally, Gentile (1998) proposed that explicit and implicit processes are two parallel learning processes mediating the acquisition of motor skills. An explicit process is associated with the mapping between the performer’s action and environment conditions, while an implicit process is concerned with the dynamics of force generation and determines efficiency of performance. Explicit and implicit learning processes, according to Gentile, are distinct but interdependent.

Implicit Sensitivity in Motor Learning

A few researchers have reported evidence of implicit sensitivity to the ‘regulatory features’ in motor learning. Pew (1974), for example, demonstrated that knowledge of the ‘regulatory features’ of a pursuit-tracking task can be learned implicitly. In Pew’s work, participants were required to track waveform patterns shown on an oscilloscope by controlling a joystick. The middle third of the patterns was repeated in each trial while the first and last thirds were random patterns. The participants were not informed of the presence of a repeating pattern. With practice, participants performed the task with significantly fewer errors on the repeated middle third part than on the random patterns. More importantly, at the end of the experiment, participants reported that they were not aware that the middle part of the pattern had been repeated in every trial. The superior performance on the repeated pattern reflected participants’ knowledge of the pattern, even they thought they were unable to describe this knowledge.

Magill and his colleagues (Magill & Hall, 1989; Magill, Schoenfelder-Zohdi, & Hall, 1990) and Wulf and Schmidt (1997) replicated Pew’s results and provided more evidence of implicit awareness in motor learning. Magill et al. (1990) used the same paradigm as Pew (1974) but moved the repeated pattern to the first part of the tracking task to make it more obvious. Participants still reported no awareness of the repeated pattern and their performance on the repeated pattern was again significantly better than on the random patterns. Wulf and Schmidt (1997) had participants practice the tracking task with different amplitude and speed scales. Participants again showed more accurate performance on the repeated pattern in both retention and transfer test with novel scaling with no awareness of repeated patterns, suggesting that the repeated pattern had been learned implicitly. Wulf and Schmidt also found a superior transfer performance when the repeated pattern was practiced with different scales randomly than constantly, suggesting that the implication of the advantages of variable practice over constant practice form the schema theory (Schmidt, 1975) can be seen in implicit learning as well as explicit learning.

Learning Motor Skills Implicitly

Research has provided encouraging evidence of efficient performance of a motor skill developed via implicit sensitivity of the environmental cues (Magill & Hall, 1989; Magill & Clark, 1997; Magill et al., 1990; Pew, 1974; Wulf & Schmidt, 1997). It is, however, quite another story to learn a motor skill itself without knowledge about the performance of that skill. While learning a motor skill, even with no explicit instructions given; the learner is very likely and may unavoidably accumulate explicit knowledge during the learning process by actively comparing his or her own actions with consequent outcomes in an effort to achieve better performance. Such a learning process that involves active comparison of actions and outcomes is associated with Hayes and Broadbent’s (1988) description of a selective mode of learning. In a selective mode of learning, the learner tests hypotheses about how best to perform a skill and selects successful actions for future performance. As a result, the learner gradually builds up a pool of technical rules of performance and explicit knowledge about the skill.

Several methods have been proposed to suppress explicit learning and encourage implicit learning processes in motor skill learning. The first attempt to teach motor skills implicitly was made by Masters (1992). He employed a dual-task methodology to teach golf putting. The rationale of the dual-task methodology is based on Hayes and Broadbent’s (1988) ‘working memory’ hypothesis which states that only explicit learning involves working memory. When the learner is required to execute a concurrent secondary task while practicing the putting task, the secondary task should occupy the limited processing resources in working memory and prevent the learner from accumulating explicit knowledge of how to putt the ball (Masters, 1992). Significantly fewer numbers of technical rules of how to putt the ball were reported by the participants in dual-task conditions than by those in explicit learning conditions, suggesting that the dual-task procedure resulted in implicit motor learning (Hardy, Mullen & Jones, 1996; Masters, 1992; Maxwell, Masters & Eves, 2000).

Maxwell, Masters, and Eves (in press) induced implicit modes of learning based on the concepts of selective and unselective modes of learning (Hayes & Broadbent, 1988). A selective mode of learning has been suggested to involve using outcome feedback in hypothesis-testing processes to produce successful learning, while an unselective mode of learning does not (Hayes & Broadbent, 1988). Maxwell et al (in press) argued that by removing outcome feedback, the learner would be forced to learn the skill in an unselective mode because there would be no information with which to test hypotheses. Maxwell et al. supported their contention by showing that practicing golf-putting without outcome feedback leads to a paucity of explicit knowledge and robust performance under a concurrent secondary task load.

Maxwell, Masters, Kerr and Weedon (in press) proposed an alternative 'errorless training protocol' to induce implicit motor learning. They argued that if the learner practices the task without making errors then there should be no need for hypothesis testing in learning to create correct action-outcome links. Therefore, avoiding or reducing errors during practice should inhibit an explicit mode of learning. Maxwell et al. (in press) compared learners who practiced golf putting from a very close distance (errorless learners) with those who practiced the task from a longer distance (errorful learners) in their experiments. They found that errorless learners acquired a smaller pool of verbalisable knowledge and demonstrated a more robust performance under secondary task load than errorful learners.

The work of Masters (1992) and Maxwell (Maxwell et al., in press; Maxwell et al., in press) provides encouraging implications for the teaching of motor skills implicitly. However, there are some obstacles to be removed before these methods can be applied to the 'real world.' The dual-task procedure (Masters, 1992) has been found to suppress performance even after 3000 trials of learning (Maxwell et al., 2000). The no-outcome-feedback methodology cannot be easily carried out on the training ground without specialist apparatus to cover up the target area and block out all the visual, auditory, and even proprioceptive sensory feedback.

Maxwell et al.'s errorless training protocol (in press) seems to be more plausible than the other methods which have been investigated. Practice of a skill in a less demanding or less dynamic condition to reduce errors is not unusual in motor skill learning, especially for beginners; however, such practice can result in less efficient performance for motor skills which need to be performed in a changing environment and even worse performance in different conditions (Magill & Hall, 1990; Wulf, Shea & Whitacre, 1998).

Masters (2000) proposed an alternative method to teach motor skills implicitly, which is 'teaching by analogy' or 'analogy learning'. He argued that teaching a motor skill by using an analogy to integrate or represent all the technical rules needed for successful execution of the skill should induce an implicit learning process. Through analogy learning, no explicit instructions about how to perform the skill need to be conveyed; all the technical rules are inadvertently practiced while the analogy is being applied. According to Masters (2000) analogy learning involves few explicit processes and will result in less explicit knowledge of the skill acquired.

Analogy learning has been discussed in a variety of domains, including pedagogy, problem solving and artificial intelligence (see Gentner & Holyoak, 1997 for a review). On most occasions, the analogy is used for learning a novel concept that has similarities to a familiar one. For example, Donnelly and McDaniel (1993) taught university undergraduate students scientific concepts (e.g., the rotation of the Earth in the solar system) using either literal rules or through analogy (e.g., the operation of a light house). They found that analogy learners were not superior in answer basic-level questions of the concept but were more capable of applying the concept to a novice situation than the rule learners. Donnelly and McDaniel (1993) proposed that using an analogy enhances learning by three possible functions. Firstly, it builds a mental structure mapping the familiar and novel concepts. Secondly, it acts like an organizer for managing information. Thirdly, it provides a direct, concrete grounding for the novel concept. Knowledge conveyed in analogy learning is not ruled-based information but a higher order relationship among rules of the concept (Gentner, 1982, 1983). Individuals who learn a new concept by analogy are found to be able to apply the concept but unable to answer questions concerning detailed rules in the concept (Donnelly & McDaniel, 1993). This characteristic of analogy learning is common to the implicit learning domain where learners have been shown to successfully operate a complex system without being able to answer questions about the underlying rule structures and mechanisms of the system (Berry, 1991; Berry & Broadbent, 1984; Hayes & Broadbent, 1988).

Masters' (2000) contention that learning a motor skill by analogy will result in unawareness of fundamental rules of the skill seems to be in line with theories and findings in the analogy learning domain. In addition, learning motor skills by analogy should not inhibit learning since the analogy will be easily carried out and require no specialist apparatus (Masters, 2000). Liao and Masters (2001) examined Masters' analogy learning contention by teaching table tennis novices topspin forehand stroke by means of a "right-angled triangle" analogy. They found that learners who learned by analogy accumulated little explicit knowledge. Their performance remained stable under a secondary task burden and their performance confidence did not correlate with their actual performance. In addition, performance was not affected by psychological pressure. These characteristics have commonly been reported in the implicit learning literature (Berry, 1996; Cheesman & Merikle, 1984; Dienes & Berry, 1997; Deines et al., 1995; Hardy et al., 1996; Hayes & Broadbent, 1988; Masters, 1992; Reber, 1993; Reed & Johnson, 1998; Willingham, Greeley, & Bardone, 1993).

Liao and Masters' work (2001) supported the notion that analogy learning will induce an implicit mode of motor learning. One explanation of why analogy learning is effective can be drawn from a combination of the working memory argument of implicit learning (Hayes & Broadbent, 1988) and the chunking theory of learning (Newell & Rosenbloom, 1981). The chunking theory of learning proposes that learning is a process in which discrete items of information needed to successfully perform the skill are chunked into higher-level memory representations. In the later stages of learning, according to Newell and Rosenbloom (1981), working memory needs only to process these chunks of information during execution of the skill, rather than dealing with numerous 'bits' of information individually. It is at this point that performance becomes efficient and automatic. Analogy learning may be a process that integrates lower-level, discrete bits of explicit knowledge into higher-level chunks and, thus, results in performance which relies on manipulation of a chunk or chunks of explicit knowledge rather than individual 'bits' of explicit knowledge.

A recent work of Liao (2001) examining the mechanism that underlies the effects of the "right-angled triangle" analogy on learning has shed some light on this argument. According to Liao, chunking is a process in which discrete 'bits' of information are integrated into a new memory representation through learning. If chunking is the mechanism which underlies analogy learning, the analogy should chunk only fundamental technical information subsumed under the analogy (relevant 'bits' of information), since chunking occurs only when the discrete 'bits' of information are relevant or meaningful to the learning process (Allard & Burnett, 1985; Allard, Graham, & Paarsalu, 1980; Chase & Simon, 1973; De Groot, 1965; Egan & Schwartz, 1979; Sloboda, 1976; Starkes & Deakin, 1984). A test of this chunking hypothesis is that the analogy should be effective when the skill has been learned using relevant rather than irrelevant rules. Two groups of novices learned to hit the topspin forehand using either the analogy relevant or irrelevant rules prior to presentation of the analogy. Performance was then tested after presentation of the analogy. The results showed that, after the analogy was presented, learners who used the relevant rules exhibited robust performance under a secondary task load, whereas, those who used irrelevant rules did not. It is concluded that chunking may be the mechanism which underlies implicit processes in analogy learning

Explicit versus Implicit Motor Learning

Given that research evidence has shown that motor skills can be learned via implicit processes, examining the difference between explicit and implicit processes in skill acquisition is important. Masters (1992) and Hardy et al., (1996), for example, compared the performance of a golf putting skill acquired either through implicit or explicit learning processes under psychological stress. They found that implicit learning processes led to more robust performance under stress than explicit learning. In addition, with the ‘no feedback’ (Maxwell et al, in press) and ‘errorless learning’ (Maxwell et al, in press) procedures, implicit motor learning has been found to result in more resilient performance under a secondary task load than explicit motor learning.

Two issues in the motor skill learning domain are closely linked with the comparison between explicit and implicit motor learning. The first issue is the influence of explicit instructions on motor skill learning. Comparing learning processes with or without explicit instructions should help to expand our understanding of the distinction between explicit and implicit motor learning. The other issue linked with explicit versus implicit motor learning is the influence of self-focused attention on motor performance. Self-focused attention refers to an inward attention to one’s performance processes while performing a motor skill (Baumeister, 1984; Baumeister & Showers, 1986). It is likely that directing one’s attention to the execution of a skill encourages explicit learning processes, because the learner is more likely to alter his or her motor output in order to achieve satisfactory performance. Examination of the effect of self-focused attention on motor performance may give us a better understanding of implicit motor learning and the mechanisms underlying performance robustness under psychological stress found in implicit motor learning (Masters, 1992; Masters, Polman & Hammond, 1993).

Explicit Instructions in Motor Learning

Green and Flowers (1991) explored the effect of explicit instructions on motor performance with a visual-motor task. They had participants learn to catch a small ‘ball’ of light moving downward from the top of the screen with a paddle on a computer monitor by means of manipulating a joystick. There were 32 possible pathways of the ball presented randomly. The pathways of the ball were especially designed so that when a jiggle occurred at about one third of the pathway, the ball would take a sharp break to the right at the end on 75% of trials; when no jiggle appeared then no breaks would occur on 75% of trials. Participants in the explicit instruction condition were verbally instructed about the special feature of the pathway, while those in the no instruction condition were not told about this 75% probability rule. After 800 trials, the uninstructed participants demonstrated significantly better performance than those who received the rule.

Findings in the work of Green and Flowers (1991) appeared to be against the general assumption that instructions enhance learning process. Green and Flowers attributed the performance decrement of the instructed learners to a processing overload in cognitive resources. Explicit instructions, according to Green and Flowers, caused effort and worry in participants as they tried to remember and apply the probability rule. This “interfered with proceduralization of the motor aspects of the task” (p.299).

Magill and Clark (1997) employed the waveform pursuit-tracking procedure (Pew, 1974) to examine the effect of explicit instructions with different probability rules. They argued that if the repeated pattern appeared 100% of the time, explicit instructions might not cause the ‘effort and worry’ effect shown by Green and Flowers (1991). Magill and Clark supported their argument by showing that instructed learners in a 100% probability condition performed as well as uninstructed learners in both the 100% and 50% probability conditions and outperformed instructed learners in the 50% probability condition. It seems that, based on the findings of Magill and Clark (1997), explicit processes are less effective than implicit processes in performing a motor skill, at least for an open motor skill (simulating ball catching and pursuit-tracking tasks are both considered as open skills). Only when informational cues needed to regulate actions (the regulatory features, Gentile, 1987) appear constantly at a 100% rate, do explicit processes become as efficient as implicit processes (Magill, 1998).

The findings of both Green and Flowers (1991) and Magill and Clark (1997) strongly hint that minimizing explicit instructions may lead to more efficient motor performance. Wulf and Weigelt (1997) provided more support for this contention in a simulated skiing task (a closed skill). The task required participants to stand on a platform of a ski simulator and move it rhythmically to the right and to the left as far as possible by making slalom-type movements. The goal of participants was to make as large a movement amplitude as possible. The key to the task is the timing of force exertion on the platform (timing of forcing). In the first experiment, explicit instructions for the optimal timing of forcing were given to one group of participants while the other group received no instructions of any form. After three days of practice (19 trials), the performance of the uninstructed learners was better (approaching significance) than that of the instructed learners. In the second experiment, all learners received no instructions about the optimal time of forcing and all improved significantly from day 1 to day 4 of practice (22 trials). Before trial 23, the optimal timing of force was given explicitly to all the learners. After receiving the instructions, a significant drop in performance occurred and it did not even recover in a retention test. Wulf and Weigelt (1997) concluded that explicit instructions hinder performance by guiding the learner’s attention to certain aspects of the movement. This may inhibit the learner’s chance to pick up more sensory information with which to adjust body movements and explore the intrinsic dynamics of the apparatus. Follow-up work by Wulf and her colleagues (Shea & Wulf, 1999; Wulf, Möß & Prinz, 1998; Wulf, Lauterbach & Toole, 1999) on skiing and golf has provided further evidence of the disruptive effects of explicit instructions on motor performance.

More recently, Hodges and Lee (1999) found that specific instructions that gave a step-by-step guide to performance resulted in slower movement time than general instructions that gave only a general principle of performance on a bimanual visual-motor coordination skill. In addition, when the skill was tested under a secondary task load (backward counting), learners who received specific instructions showed a more serious decrement in performance than those who received general instructions or no instructions. It appears that explicit instructions increase the cognitive demand of performing a motor skill. According to Hodges and Lee (1999), the more explicit instructions given the more cognitively demanding the skill becomes, because learners need more time to 'implement' the instructions they receive. Or, alternatively, these findings can be accounted for by the notions of Masters (1992) that the more explicit instructions given, the more explicit knowledge to be manipulated in working memory.

Self-focused Attention and Motor Learning

Explicit instructions may not only hinder learning but may also undermine performance under psychological stress. In the work of Wulf and Weigelt (1997, Experiment 1), participants were informed that their performance would be evaluated by a skiing expert through a one-way mirror, prior to the last trial. Although there was actually no one in the next room, this manipulation was shown to be effective by retrospective interviews with participants. Uninstructed participants performed significantly better than instructed participants in this stress intervention. Wulf and Weigelt's (1997) findings are in line with the findings of Masters (1992) and Hardy et al. (1996) that inhibiting explicit learning processes led to a stress resistant performance, suggesting that "knowing or at least thinking too much about the skill to be performed is particularly disadvantageous in more stressful situations" (Wulf & Weigelt, 1997, p. 366).

The role of attention to the performance process in performance failure under psychological stress has been emphasized by several researchers. Baumeister (1984), for example, proposed that 'choking' (performance breakdown) under stress may be due to self-focused attention caused by the desire to perform well. He argued that focusing attention on one's own performance processes to control the execution of the task would disrupt the automatic nature of the performance. Baumeister (1984), in the first and second experiments, demonstrated a hampered performance by asking participants to focus on their own hand while performing a ball-rolling task. In the third experiment, participants who were habitually unaware of their own performance processes (measured by the Self-consciousness Scale - Fenigstein, Scheier & Buss, 1975) suffered a more serious performance decrement while their attention was directed to the hand than those who were more used to self-focus. In the fourth and fifth experiments, psychological stress was evoked by either a fake co-actor or monetary incentive, respectively. Under these stress interventions, participants who were not used to self-focus again performed worse than those who were. The results of the fifth experiment, which was conducted at a video game arcade, showed that simply offering reward money for better performance ironically undermined skillful performance on a video game. Baumeister concluded that psychological stress hampers performance by causing self-focused attention, although his experiments did not provide direct evidence for the relationship between stress and self-focused attention. That is, he showed that both stress and self-focused attention will result in skill failure but not whether stress leads to self-focused attention. Baumeister also argued that individuals who do not habitually pay attention to their own performance processes while executing a skill are more likely to choke under psychological stress than those who do.

Masters and his colleagues (Masters, 1992; Masters et al., 1993) proposed a reinvestment hypothesis which extends Baumeister's self-focused attention hypothesis. They argued that explicit knowledge about the skill (acquired during learning) is critical to the skill's vulnerability to psychological stress. Under stress, the performer will attempt to control execution of the skill by applying the explicit knowledge he or she possesses. This reinvestment of explicit knowledge will, ironically, interfere with the automatic execution of the skill. Thus, the more explicit knowledge the performer possesses, according to Masters (1992), the more likely the skill will fail under stress. With a golf-putting task, Masters (1992) and Hardy et al. (1996) have both shown that performers who possess more explicit knowledge of their skill are more vulnerable under stress. In addition, Masters et al. (1993) suggested that reinvestment of conscious control in the performance process may be a dimension of personality. They found that individuals who tend to self-monitor their own actions and think more about what they are doing are more likely to choke when under psychological pressure.

Both Baumeister (1984) and Masters et al. (1993) point out that self-focused attention plays a mediating role in the linkage between psychological stress and performance failure. The ground on which their contention is based, however, seems to be controvertible. Baumeister (1984) and Masters et al. (1993) provided no evidence that psychological stress induces self-focused attention, although Baumeister demonstrated that focusing on one's own hands caused a similar performance decrement to psychological stress. More direct evidence of the relationship between psychological stress and self-focused attention is needed. Recently, Liao and Masters (2002) adopted a time-to-event paradigm (Martens, Vealey & Burton, 1990) to examine this relationship. The rationale for the paradigm is that levels of perceived stress should vary before and after an important event (e.g., a crucial ball game). Variables (e.g., emotion) which are hypothesized to be associated with perceived stress should vary accordingly. If self-focused attention is related to psychological stress, levels of self-focused attention measured before and after an important event should vary in association with levels of perceived stress. Liao and Masters (2002) assessed university hockey players' levels of self-focused attention as well as anxiety two days before, two hours before, and two days after a crucial semi-final match. The hockey players' self-focus levels were relatively high before the stressful semi-final match but dramatically decreased afterwards, suggesting a significant effect of psychological stress on self-focused attention.

In addition, Baumeister (1984) and Masters et al.'s (1993) notions of how the effect of psychological stress on performance will be affected by self-focused attention appear to conflict. Baumeister argued that the acclimatization to self-focused attention will lead to robust performance under psychological stress because the performer will be used to performing under self-focused attention caused by stress. Masters et al., however, suggest that habitually performing a skill under self-focused attention will result in a large pool of explicit knowledge of this performance. Performance will suffer a serious decrement under psychological stress due to the reinvestment of this large pool of explicit knowledge to control execution of the movement. In an attempt to end this controversy, Liao and Masters (2002) examined how performance of a motor skill that had been practiced under self-focused attention was affected by psychological stress. They found that basketball novices who were instructed to focus on the mechanics of the ball shooting process during practice suffered a significant performance decrement in a subsequent stressful test phase, whereas, those who were required only to do their best during practice showed no degradation in performance. Liao and Masters (2002) suggested that self-focused attention may increase in response to psychological stress, and that the negative effect of self-focused attention on performance under stress is likely to be magnified if the skill is practiced under self-focused attention.

Implications

Literature reviewed in this paper have several implications in implicit motor learning. Firstly, Hayes and Broadbent's (1988) contention that the utilization of working memory dissociates explicit from implicit functions may well be applicable in motor skill learning. Motor performance mediated by explicit processes appears to involve working memory and is subject to difficulties when a concurrent secondary task loads the limited resources of working memory. Implicit motor learning, on the other hand, utilizes few processing resources in working memory and performance is less likely to be affected because there are spare resources for processing the secondary task. The addition of a secondary task is not the only way to overload the processing resources of working memory. Worries caused by psychological stress have also been suggested to impose a load (e.g., Eysenck, 1992). The finding that psychological stress has little effect on motor skills acquired through less explicit processes (e.g., analogy learning, Liao & Masters, 2001) also provides support for the contention that implicit motor processes avoid the involvement of working memory.

Psychological stress is associated with high levels of attention to the performance process. Explicit knowledge appears to be the intermediary which detonates this negative relationship between stress and high levels of self-focused attention. The working memory hypothesis of implicit learning (Hayes & Broadbent, 1988) and the reinvestment hypothesis of explicit knowledge (Masters, 1992; Masters et al., 1993) both provide plausible explanations of the harmful effects of conscious control on performance. Both hypotheses point out that the manipulation of explicit knowledge causes disruption to performance, but the working memory hypothesis emphasizes the overloading of limited processing resources in working memory, while the reinvestment hypothesis emphasizes the disruption of automaticity of performance. A combination of both hypotheses may provide a clearer description of the phenomenon of performance breakdown under psychological stress than either hypothesis alone: psychological stress causes worries about task performance, which occupy resources in working memory (Eysenck, 1992); psychological stress also engenders the reinvestment of explicit knowledge in order to control performance, which also needs resources in working memory. Therefore, under stress, the skill is executed in a state in which more processing resources are needed because of the reinvestment of explicit knowledge, but, at the same time, only few resources, if any, are available due to worry. This interaction effect makes performance more vulnerable under psychological stress.

Since performance is more likely to fail when the performer has more explicit knowledge with which to control performance, learning a skill implicitly should lead to robust performance. Learning a motor skill in a totally implicit condition on the training ground may be impractical or impossible. Nevertheless, previous researches implies that explicit instructions should be minimized and knowledge of the skill should not be allowed to accumulate through self-interpretation of the performance processes. Explicit and implicit learning should not be treated as two dichotomous learning processes, they should be treated as at the two ends of a continuum (Magill, 1998). Strategies that create a learning condition with a bias towards the implicit learning end are likely to be helpful. Analogy learning and other techniques proposed in the literature (e.g., errorless learning: Maxwell et al., in press) are examples of the application of this principle.

Future studies may consider the effect of implicit learning strategies on different types of motor skill. Magill (1998), for example, has proposed that the ‘regulatory features’ (relevant reaction cues in the environment) of an open motor skill can be, and should be, learned through implicit processes, implying that an open skill will benefit more from implicit learning than a closed skill. Gentile (1998), on the other hand, proposed that the linkage between action and environment conditions is associated with explicit process, while implicit processes underlie the dynamics of force generation. Gentile’s contention seems to imply that a closed skill will benefit more from implicit learning than an open skill. Although robust performance results from implicit learning have been demonstrated in both closed (golf-putting: Masters, 1992; Maxwell et al., in press) and open skills (table tennis: Liao & Masters, 2001), implicit processes may contribute differently in the acquisition of closed and open skills.

In addition, implicit learning strategies may have different effects on learners with different personalities. Masters et al. (1993) have shown that individuals may have differential predispositions to focusing their attention inwards to the mechanics of their actions and react differently to psychological pressure. It is possible that learners who are prone to monitor and analyze their own behaviours, will, for example, habitually try to dissect and interpret information they receive about how to execute a new skill. They will be likely to form a pool of explicit knowledge about the skill from their own dissection and apply it during learning and performance.

Finally, issues concerning how implicit and explicit processes interact with each other may be of particular interest in motor skill learning. Gentile (1998) has suggested the importance of a balanced development of both explicit and implicit knowledge in motor performance. Willingham and his colleagues (Willingham, 1998; Willingham & Goedert-Eschmann, 1999) have argued that implicit learning takes place in parallel with explicit learning when a motor skill is practiced. They also argued that the automaticity of motor performance at the later stage of learning is not due to the transformation of explicit to implicit processes as implied by Anderson (1982). Implicit and explicit knowledge develop in parallel with each other, according to Willingham and Goedert-Eschmann (1999), and over practice the former gradually takes over the role of supporting performance from the latter. More research is certainly needed to clarify this issue and it may help to gain more insight into the mechanisms which underscore implicit motor learning.

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運動學習與表現的內隱與外顯歷程

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摘要

知識的獲得可以經由外顯的與內隱的兩種歷程。經由外顯的學習歷程所獲得的知識是可以用語言表達的；經由內隱的學習歷程所獲得的知識是無法或很難用語言表達出來的。這兩種歷程的特性已經引起心理學研究者多年的注意，近年來，在運動科學領域也有一些研究者開始探討運動學習與表現的內隱歷程。本文，透過文獻探討與分析，檢驗外顯的與內隱的歷程在運動技能學習與表現所扮演的角色，以及幾種可能助長內隱學習歷程的方法。此外，與外顯的與內隱的學習歷程有關的因素，如練習時給予學習者的口語指導，以及心理壓力所產生的「自我集中注意」，也加以討論。

關鍵詞：外顯歷程、內隱歷程、內隱學習、口語指導、自我集中注意