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LEARNING A MOTOR SKILL: EFFECTS OF BLOCKED VERSUS RANDOM PRACTICE A REVIEW

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Procedural learning refers to the ability to learn new perceptual, motor or cognitive skills. While many studies have explored procedural learning abilities in patients with different types of brain damage, the cognitive mechanisms involved in the acquisition of a new skill are still not well understood. The present review focuses on the conditions that optimise skill acquisition, and more specifically on the contextual interference effect (CIE), which refers to the advantage of a 'random' over a 'blocked' practice condition in skill learning tasks. According to both the 'elaboration' and 'reconstruction' hypotheses, the CIE can be explained by the fact that the random schedule requires more cognitive activity than the blocked one. However, if the CIE has been consistently demonstrated in laboratory studies, it is not so clear in field-based studies. We discuss this 'laboratory and field dilemma', and suggest that two main factors – task complexity and individual variables – may explain the discrepancy between the two types of studies.

Introduction

Procedural learning is a concept that has been studied a good deal in recent years (e.g., Anderson, 1992; Beaunieux, 2006; Churchill, Stanis, Press, Kushelev, & Greenough, 2003; Deweer, Ergis, Fossati, Pillon, Boller, Agid et al., 1994; Osman, Wilkinson, Beigi, Castaneda, & Jahanshahi, 2008). According to Cohen and Squire (1980), it refers to our capacity to progressively acquire new skills thanks to long and repetitive training. These skills are stored without conscious reference to previous experience. The interest in procedural learning is motivated by its direct links with our day-to-day life: driving a car, playing chess, reading, etc. However, many questions remain unanswered regarding the cognitive mechanisms involved in the acquisition of a new skill and the conditions that optimise skill acquisition. In this review, we will focus specifically on the importance of the organisation of training in the acquisition of a new skill. When learning a new perceptuo-motor skill, is it preferable to practise the skill in a repetitive and structured way, or would the skill acquisition be more rapid and/or generalisable (i.e., transferable to new situations)

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when the learning conditions are more variable and randomly organised? This question is important not only to better understand the mechanisms underlying procedural learning, but also from a clinical point of view. Indeed, in clinical settings (e.g., in the rehabilitation of amnesic patients), some of the rehabilitation strategies applied to memory-impaired patients depend on their procedural abilities, which are often preserved. In this context, a better understanding of the optimal conditions in which new procedural skills can be learned should help clinicians to develop more efficient rehabilitation programmes.

Different studies have explored the effects of the organisation of practice on the acquisition of a new motor skill. Generally, two learning conditions are contrasted: a high-variability condition, in which the training trials are arranged randomly, and a low-variability condition, in which the training trials are organised in a more constant way. More specifically, low variability is produced when subjects complete all the trials corresponding to one variation of a movement before performing another variation (e.g., AAA, BBB, etc.). This situation is typical of blocked practice. On the other hand, high variability is produced when the variations are presented in an unpredictable order (e.g., ACB, BCA, etc.), as is typical in random practice. The studies that have explored this contrast generally show that, while the random practice condition leads to poorer performance during acquisition than the blocked practice condition, it yields superior performance on a retention or transfer test, a phenomenon that is commonly called the *contextual interference effect (CIE)* (Battig, 1966; Shea & Morgan, 1979).

Battig (1966) was the first to study the effect of a blocked versus random organisation of the learning material in verbal learning studies; in later papers, he used the term ‘contextual variety’ instead of ‘intratask interference’ (Battig, 1972). Finally, he adopted the term ‘contextual interference’ (Battig, 1979). He chose this term because ‘contextual interference’ emphasises the roles of contextual factors that are internal and external to both the task and the learner (Battig, 1979; Magill & Hall, 1990). In other words, the entire practice context, including the task, the practice schedule, and the processing engaged in by the learner, were seen as potential sources of interference that could enhance (or reduce) learning. In the motor learning literature, ‘contextual interference’ refers specifically to the way interference is introduced into the practice schedule.

In this review, we will discuss the CIE in motor learning, in five sections. The first section will summarise the laboratory experiments that have studied the CIE. The second section will be devoted to the different theories that have tried to explain the CIE. The third section will review field-based research which, in contrast to laboratory experiments, uses more ecological tasks. In the fourth section, we will highlight the influence of certain factors on the

CIE, such as the characteristics of the tasks or the subjects. In the fifth section, we will examine the clinical relevance of the CIE. We will close this review with a conclusion in which we suggest some leads for future studies of the contextual interference effect.

Laboratory studies

In 1979, Shea and Morgan were the first to study the CIE in motor learning; to do so, they used the Barrier Knock-Down Task. In this task, subjects have to move their arm through three different patterns as quickly as possible, in response to a stimulus light: picking up a tennis ball with the hand, knocking over a series of three freely moveable wooden barriers, and then returning the ball to a final location. The dependent variable is the time recorded between the onset of the stimulus light and the arrival of the ball in its last location. Contextual interference is incorporated into the practice schedule by using a blocked practice schedule, representing a low level of contextual interference, and a random practice schedule, representing a high level of contextual interference. In the blocked schedule, subjects practise all the trials corresponding to one of the movement patterns before practising another pattern, whereas in the random schedule, the practice trials for each pattern are randomly distributed. Shea and Morgan documented the existence of the CIE with this task. Indeed, during the acquisition phase, the blocked schedule group performed better than the random schedule group, whereas on the actual task subjects who had practised the patterns in a random schedule outperformed those who had practised according to a blocked schedule. Other researchers have subsequently used the same paradigm (Carnahan, Van Eerd, & Allard, 1990; Gabriele, Hall, & Buckolz, 1987; Gabriele, Hall, & Lee, 1989; Lee & Magill, 1983; Lee, Wulf, & Schmidt, 1992; Sekiya, Magill, Sidaway, & Anderson, 1994; Shea & Zimny, 1983; Simon, 2007; Wulf & Lee, 1993) and they all obtained the same results as the pioneering study by Shea and Morgan (1979).

Another task that is often used in this domain is the Anticipation Timing Task (Del Rey, 1982; Del Rey, Wughalter, & Carnes, 1987; Del Rey, Wughalter, & Whitehurst, 1982; Overdorf, Schweighardt, Page, & McGrath, 2004; Smith & Rudisill, 1993). A Bassin Anticipation Timer is made of two attached 16-lamp runways, which are placed on a table. The subject is placed in front of both the runways and the response button. The instructions are to press the response button when the final lamp on the runway lights up. Dependent variables are the magnitude and the direction of each participant's error in anticipating the light's 'arrival' at the end of the runway. The variability depends on the speed of the light flashes. Studies that have used this task have shown a CIE: while the random practice condition led to poorer performance during acquisition than the blocked practice condition, it yielded superior performance on a retention or transfer test.

The CIE has been demonstrated in other studies using different experimental tasks: the Force Production Task (Shea, Kohl, & Indermill, 1990), in which subjects have to hit the padded arm of a force transducer to elevate a trace dot on the oscilloscope to different target lines; the Computerized Maze Task (Jelsma & Pieters, 1989; Jelsma & Van Merriënboer, 1989), in which subjects use a joystick to duplicate four different complex forms, the original form being modified through effects such as rotation or mirror effects; and the Photoelectric Rotary Pursuit Task (e.g., Heitman, Pugh, Kovaleski, Norell, & Vicory, 2005; Smith, 2002), in which participants use a handheld pointer to track a small illuminated target located on the edge of a rotating turntable.

A few studies, however, obtained contradictory results. For example, Lage, Vieira, Palhares, Ugrinowitsch, and Benda (2006) did not find a CIE with the Positioning Timing Task (Gabriele, Lee, & Hall, 1991; Shea & Morgan, 1979). This task consists in transporting three balls in six numbered containers according to pre-defined sequences within a specified movement time. An electronic device is used to measure reaction and movement time; it contains a stimulus light and a button to control the beginning and the end of the task. According to Lage et al. (2006), the CIE could be linked to the criterion time: more specifically, the absence of a CIE might be explained by the additional demand posed by the constrained movement time. Thus, the procedure might have enhanced the difficulty of the cognitive processing in the constant practice group (because the subjects had to 'adjust' the movement time at each trial), thereby suppressing the contrast between the two conditions. This hypothesis is supported by the fact that, in a previous study with the same task, Gabriele et al. (1991) obtained the CIE by asking the subjects to simply transport the balls as quickly as possible, whereas Lage et al. (2006) imposed a criterion time of 2,700 ms at each trial.

Another contrasting result was obtained by Maslovat, Chua, Lee, and Franks (2004) with the Bimanual Coordination Task (Tsutsui, Lee, & Hodges, 1998). In this task, the subjects have to move their arms from side to side so that three bimanual coordination patterns can be produced. More specifically, they grasp two handles that move in parallel along a trackway on the table and must learn how to move their arms in such a way as to produce the pattern displayed on the computer screen. The right arm leads the left arm by either ⅛ of a complete cycle, ¼ of a complete cycle, or ⅜ of a complete cycle. Contrary to Tsutsui et al. (1998), Maslovat et al. (2004) did not obtain a CIE with this task, observing that the random group outperformed the blocked group during the acquisition phase. This result can probably be explained by the fact that their subjects were given a high number of acquisition trials and practice trials prior to acquisition, which may have allowed sufficient time for the learning benefits of interference to be realised and expressed during acquisition rather than retention. However, as expected, the random group outperformed the blocked group in retention and transfer.

To sum up, even though some exceptions have been observed, we can conclude that the CIE is a robust phenomenon in laboratory studies. The unexpected results have generally been explainable by some particular methodological characteristics of the tasks used.

Theoretical explanations

In this section, we will discuss the main concepts applied to explain the CIE based on laboratory studies. In other words, what are the learning processes influenced by manipulations of the practice schedule? Different theories have tried to explain this phenomenon; indeed, although the existence of the CIE in laboratory studies is widely accepted, there is little consensus about the reasons for its emergence. We have found four main theoretical perspectives that attempt to account for the CIE: the elaboration hypothesis (Shea & Zimny, 1983), the action-plan reconstruction hypothesis (Lee & Magill, 1983), the Retroactive Inhibition Explanation (Davis, 1988; Meeuwsen & Magill, 1991), and Schmidt's schema theory (Schmidt, 1975, 1988).

The elaboration hypothesis

According to this theory, new skill learning can be sustained by two different kinds of processes: intra-task and inter-task. Intra-task processing involves the analysis of an individual task, without reference to any information directly related either to another task being acquired (which could be a variant of the task in hand) or to other extant knowledge. In contrast, inter-task processing aims to highlight, through between-task analyses, the similarities and differences between the tasks being acquired. Regarding the CIE, the idea is that a blocked schedule requires only intra-task processing, whereas a random schedule calls for both intra-task and inter-task processing. In the blocked schedule, only one task resides in working memory at a time, which explains the requirement for intra-task processing. On the other hand, in the random schedule, several tasks are present simultaneously in working memory. Thanks to the possibility of identifying similarities and differences among the tasks, inter-task processing allows a better mnesic representation than the blocked condition linked to intra-task processing.

Several empirical observations support this theory. Shea and Zimny (1988) recorded the verbal responses of subjects following practice under random and blocked conditions. Their results show that subjects under the random condition made more comparisons between tasks and constructed a number of different strategies that proved to be beneficial for learning. Limons and Shea (1988) also supported this view, postulating that recognition was primarily dependent upon intra-item elaboration, while recall performance necessitated inter- and intra-item processing. In their experiment, they administered the barrier knock-down task to 72 students. Two levels of contextual interference (blocked versus random) were crossed with two levels of recognition training (no recognition training [NT] versus recognition training [T]). Concretely, subjects in the T condition received recognition training (i.e., they had to study three diagrams depicting the tasks they would practise and then identify them among six other non-studied diagrams) before acquisition practice. Subjects in the NT condition were given no recognition training before the acquisition phase. All subjects received identical tests for retention 10 minutes after acquisition. Finally, subjects were given a recognition test which consisted of identifying the three task diagrams practised during acquisition from among six other distracter task diagrams. The results showed that the blocked and random subjects performed equally well on a recognition list, while the blocked subjects were less efficient at recalling movement information. The authors concluded that blocked and random schedules led to differential processing.

Other researchers (Wright, 1991; Wright, Li, & Whitacre, 1992) carried out another type of experiment to support the elaboration hypothesis. They manipulated the type of processing by supplementing the blocked practice with additional inter-task or intra-task processing. Concretely, they managed to increase the level of inter-task processing by asking subjects, after each trial, to look at a figure with the movement pattern of one of the other two movement patterns (belonging to different blocks) and to identify the similarities between them. Intra-task processing was increased by asking subjects to verbalise the pattern of movement they had just performed. The results showed that the blocked group with additional inter-task processing was able to perform as well as the typical random group. This confirms that inter-task processing is essential, or at least important, for skill learning. However, this effect was limited: the authors added inter-task processing to the random schedule and this manipulation caused a delay in acquisition. Increasing cognitive demands during random practice, by the addition of extra processing, appears to create an overload phenomenon. They also observed retention performance equivalent to the typical random results.

The action-plan reconstruction hypothesis

Several authors (Lee & Magill, 1983; Lee, Magill, & Weeks, 1985) have tried to account for the CIE by calling on a ‘reconstruction’ mechanism that takes place in the random practice condition. Their main idea is that random practice requires more effortful processing on each trial because the information related to the action plan for the current trial has been forgotten as a result of practising the intervening movements. So, for each trial, the participant must reconstruct a new action plan before executing the next movement. For the blocked practice, on the other hand, an action plan that is appropriate for an upcoming trial is still active in working memory from the preceding trial. Thus, reconstructive activity in blocked practice may be minimised relative to random practice. According to the action-plan reconstruction hypothesis, reconstructing the action plan at each trial generates a better ability to create appropriate responses when the learner is confronted with a new transfer task (i.e., performance on this transfer task benefits from the learner's ability to create or reconstruct new action plans).

Lee, Wishart, Cunningham, and Carnahan's (1997) results support the action-plan reconstruction hypothesis. Three practice groups were compared in their study: random practice, blocked practice, and a random practice group for which a model was provided prior to each trial. Lee et al. (1997) predicted that providing a template of the next trial should prevent the forgetting and the consequent need for action-plan reconstruction processing. Their results support this view since participants in the random practice condition with modelled information performed similarly to the blocked group on both the acquisition and retention tests (for similar results, see also Li & Wright, 2000).

According to Immink and Wright (1998), if the basic principle underlying the reconstruction view is correct, one can expect that random schedule subjects may need more time to complete their preparation of upcoming movements than their blocked practice counterparts. To test this prediction, they allowed participants to choose how long they viewed stimulus material to plan an upcoming movement. More specifically, sequences of letters were presented and subjects had to reproduce them on a computer keyboard. The instruction was to look at the letters on the screen for as long as it was necessary to be able to reproduce the sequence quickly and accurately. Three different combinations of four keys were used and participants practised them in either a blocked or a random practice condition. In the blocked schedule, subjects practised all the trials corresponding to one of the sequences before practising another sequence, whereas in the random schedule, the practice trials for each sequence were randomly distributed among all the practice trials. As predicted by the reconstruction explanation, the study time decreased faster and reached a lower asymptote during blocked practice than during random practice.

Cross, Schmitt, and Grafton (2007) examined the neural substrates of the CIE by using functional magnetic resonance imaging (fMRI). To do this, they used Immink and Wright's (1998) task version. Subjects learned a set of three four-element sequences, presented on a computer, according to a blocked or random practice schedule. More specifically, each subject positioned the four fingers of his or her hand on the four light-sensitive response keys of a fibre-optic keyboard to reproduce the sequences. This study employed a design to measure between-group brain activation differences when participants studied movement sequences and when they performed them. Their results confirmed the presence of the CIE. The imaging data revealed greater activity within sensorimotor areas during movement preparation and showed that the random group engaged in more movement preparation than the blocked group, a result consistent with the reconstruction hypothesis. The authors claimed that the increased activity within both the superior frontal gyrus and the middle frontal gyrus during movement execution suggests that, by the end of their training, participants in the random group were recruiting additional higher cognitive areas involved in executive control.

Retroactive inhibition explanation

The hypotheses described above generally explain the CIE as resulting from the advantages of random practice over blocked practice for retention and transfer. The retroactive inhibition hypothesis, on the other hand, focuses on the disadvantages of a blocked schedule. Specifically, Poto (1988) proposed that a blocked schedule is disadvantageous because of a retroactive interference effect. Considering that performance on any retention test might be influenced by some combination of retroactive and proactive interference, Poto administered a task in which subjects went through a blocked schedule consisting of a block of task A, then a block of task B, and finally a block of task C. They were tested later on all three tasks. In this task, retroactive interference may influence the performance of tasks A and B, while proactive interference may influence the performance of tasks B and C. The results showed that the farther from the retention test a task was practised, the poorer the retention performance was. Thus, retroactive interference appeared to be the primary source of poor retention test performance. However, on the basis of this information, we cannot rule out a simple effect of lapsed memory (i.e., an effect that is more marked for old knowledge and less so for recent knowledge).

In his review, Brady (1998) cites a series of experiments that support the retroactive inhibition hypothesis. For example, Meeuwsen (1987, cited in Brady, 1998) observed that a blocked practice group given a retention test after each trial block (and thereby eliminating retroactive inhibition) presented better results than a typical blocked group. He concluded that the worse performance after blocked practice, compared to random practice, might result from retroactive inhibition. Shea and Titzer (1993) examined the influence of reminder trials on contextual interference. Three motor tasks were performed under a random or blocked schedule, with either one reminder trial or none for each task at the end of the practice session. They found no significant differences between the random group and the blocked group that received a reminder trial, but they observed a CIE between the typical blocked group (without a reminder trial) and the random group. This observation also supports the retroactive inhibition hypothesis (see also Shewokis, Del Rey, & Simpson, 1998).

Schmidt's schema theory

This theory, which is often linked to CIE theory, also tries to explain the effect of the organisation of practice on the learning and retention of a new skill.

Schmidt's schema theory (Schmidt, 1975, 1988) is based on two elements: a Generalised Motor Programme (GMP) and rules of parameterisation. A GMP is not a specific movement but a class of movements. The parameterisation rules allow the GMP to be adapted to the specific nature of the task.

This theory is organised around three elements that are specifically relevant to new motor skill learning. Firstly, GMPs control movement production (e.g., tossing movement). Specifically, a particular GMP governs the movements which belong to the same class because they share certain invariant features such as timing or sequencing. Secondly, schemata provide scaling characteristics (i.e., parameters) to the GMP, allowing subjects to perform specific movements within the given class (e.g., long-distance toss vs. short-distance toss). For example, if the tossing has to be performed over a short distance, the invariant features of the GMP controlling the tossing movements remain unchanged, but the force parameter decreases. Third, thanks to the movement variations during practice, schemata are formed and strengthened. In other words, the strength of the schema is a function of practice variability. In comparison, constant practice does not support schema formation. More specifically, it is suggested that practice variability forces individuals to continuously (i.e., at each trial) parameterise the motor programme and allows the building of effective parameterisation rules. On the other hand, repetition of the same movement only allows reinforcement of a specific motor programme; in this context, the subject cannot learn to adapt to changing conditions.

Shea and Morgan (1979) proposed a link between Schmidt's schema theory and CIE theories (i.e., the elaboration hypothesis and the action-plan reconstruction hypothesis) because both address the idea that practice variability leads to improved learning. However, Newell (2003) highlights the fact that Schmidt's schema theory makes no prediction about the structure of the practice variability. Indeed, only the amount of variable practice is manipulated, with little attention to the practice schedule. In the CIE theories, on the contrary, the amount of variable practice is held constant while the practice sequence changes. In spite of this difference, the two kinds of theories provide complementary reasons for the advantages of random over other forms of training: random practice strengthens schemas in Schmidt's schema theory while, in the CIE theories, random practice enhances retention and transfer through elaborative encoding and/or repeated reconstruction of the action plan during acquisition.

Conclusions

Several researchers have argued that these rival theories may not be mutually exclusive and that they share a common denominator (Gabriele et al., 1989; Smith & Rudisill, 1993; Young, Cohen, & Husak, 1993). This common denominator might be the enhanced cognitive activity or the more effortful processing engendered by random practice schedules and the poor or decreased processing resulting from a blocked schedule. In other words, practice manipulations that require more cognitive effort (i.e., random schedule) are predicted to be more effective for motor learning than practice manipulations that require less cognitive effort (i.e., blocked schedule; Sherwood & Lee, 2003).

So, according to both the elaboration and reconstruction hypotheses, a random schedule requires more cognitive activity. But the first hypothesis explains this increase by the participants' engagement in inter-task elaborative processing, whereas the second relies on the assumption that subjects have to reconstruct an action plan after each trial. In fact, Keller, Li, Weiss, and Relyea (2006) consider that both these viewpoints highlight an important role for top-down executive control processes, such as response selection, task comparison, and the effortful processes involved in the reconstruction of an action plan.

Field-based studies

We have seen that many laboratory-based studies have led to results confirming the presence of the CIE (for reviews, see Brady, 1998, 2004, 2008; Magill & Hall, 1990). However, such laboratory tasks may be very different from real-world situations. Several authors (Hoffman, 1990; Newell & Rovegno, 1990; Singer, 1990) have stressed the lack of ecological validity or fidelity of these basic research projects, which were specifically designed to isolate particular processes or environmental demands. In order to provide rapid gains, the experiments tend to be relatively simple. Goode and Magill (1986) argue that greater congruity must exist between laboratory and field-based research and that minimal motor demands must be avoided. If the goal is really to understand motor skill learning and to make recommendations for the training of motor skills in the real world, it is important to study the acquisition and learning of more complex skills that pose greater challenges for the participants' cognitive capacity.

In recent years, some authors have attempted to respond to this lack of ecological validity. In the following paragraphs, we will present some applied studies that demonstrated the CIE (at least regarding the transfer phase), and some that failed to show the CIE or obtained mixed results.

Different studies have used sports situations to test the CIE. Hall, Domingues, and Cavazos (1994) trained their subjects on baseball batting. They practised with three kinds of pitches: change-up pitches, fastballs, and curveballs. No significant difference was found between blocked and random practice during the acquisition phase, but the random group outperformed the blocked group during the transfer test. Memmert (2006), who used a basketball skill, also obtained results supporting the CIE. In this study, two groups were compared: the constant group made shots from the same position, while the shooting position of the random group changed at each trial. A typical CIE was found: the constant group outperformed the random group during acquisition, while the random group was more efficient in both the retention and transfer tests. Likewise, the CIE has been observed in a rifle shooting learning task (Boyce & Del Rey, 1990) and a ballistic aiming task (Keller et al., 2006).

Other studies have tested the CIE with computer games. For example, in Shewokis's (1997) study, the participants played different games randomly or in a block schedule (one game after the other). The random group performed better in a transfer situation, which involved a cross-country skiing game.

On the other hand, several ecological studies have failed to demonstrate the CIE. For example, in a first series of studies on basketball skill acquisition, no benefit was observed for the random groups in comparison with the blocked groups: Crumpton, Abendroth-Smith, and Chamberlin (1990) found no effect of the contextual variability of practice on the acquisition of a throwing skill (i.e., free throw, jump shot, and lay-up; see also Landin & Hebert, 1997), while Chamberlin, Rimer, and Skaggs (1990; see also Shoenfelt, Snyder, Maue, McDowell, & Woolard, 2002) did not observe the CIE for a shooting skill in a situation in which the distance between the shooting position and the target varied. The CIE was only partially present in a study by Goode and Magill (1986), who compared different serves (long, short, and drive serves) and showed the CIE (in both the retention and transfer tests) only in the short serve condition. In a similar study, Wrisberg and Liu (1991) introduced two contextual interference levels on long and short serves. Again, there were no differences in acquisition, whereas the random group had significantly higher retention scores on the short serve. However, in transfer, both kinds of serves showed evidence of the CIE. Another basketball study (Landin & Hebert, 1997) compared traditional schedules (blocked and random) with a blocked-serial schedule, which involves a more moderate level of contextual interference (CI). Participants assigned to the constant condition performed six successive trials from each position. Those practising under the moderate CI schedule performed three successive trials at each location and repeated the sequence twice. The random condition involved performing one trial per position in a serial arrangement and repeating the sequence six times. The results showed that a moderate level is more efficient than either the blocked or random practice schedules. Proteau, Blandin, Alain, and Dorion (1994) attributed this superiority to the notion that the moderate schedule combined the best of the high-CI and low-CI schedules. That is, it allowed repeated trials under one condition, which facilitated error correction, but also provided the interference of changing tasks.

Other negative results were obtained in studies exploring volleyball skills (e.g., serve; French, Rink, & Werner, 1990; Jones & French, 2007; Sears & Husak, 1987; Zetou, Michalopoulou, Giazitzi, & Kioumourtzoglou, 2007; but see Bortoli, Robazza, Durigon, & Carra, 1992, for contradictory results on volleyball serves) and golf-related skills (Brady, 1997; Goodwin & Meeuwsen, 1996). In these latter studies, the variability manipulation concerned either the type of task (e.g., drive, pitch, chip shot) or the distance of the target. Soccer- (Li & Lima, 2002) and darts-related skills (Goodwin, Grimes, Eckerson, & Gordon, 1998; Meira & Tani, 2001; Moreno, Avila, Damas, Garcia, Luis, Reina et al., 2003) were also studied and did not show any CIE.

Pollatou, Kioumourtzoglou, Agelousis, and Mavromatis (1997) investigated the learning of two skills: throwing and kicking a ball. Significant improvements in performance were found in all groups for both tasks. However, the authors showed that random practice provided better retention, but only for the throwing task and not for the kicking.

Wegman (1999) examined the CIE through three different skills: ball rolling, racket striking, and ball kicking. The blocked conditions gave better results at the end of the training, and the random group got a better result in the retention test but only for the racket striking skill. The author concluded that these results could be linked to the fact that the subjects were already familiar with that sport.

To conclude, the CIE is observed more in laboratory than field-based research. Barreiros, Figueiredo, and Godinho (2007) showed that the CIE was clearly observed in 29 percent of the studies analysing the acquisition phase (in this situation, performance was better for the grouped than the random schedules). Greater support was found for the retention phase. In fact, in 42 percent of the studies, better retention performance was a consequence of a high level of interference in the acquisition phase. The CIE is of similar magnitude in the transfer phase (43%). Thus, it appears that more than 50 percent of the studies do not support the effect at all, an observation that reflects the fact that the effect is relatively weak in applied settings. Moreover, in a meta-analysis of the CIE based on 137 estimated effect sizes from 61 studies, Brady (2004) showed that the mean effect size for laboratory research (.57) is significantly higher than for field-based research (.19).

In conclusion, the results of the field-based studies are equivocal. The differences between the results of laboratory and ecological experiments may be linked to a number of factors on which we will focus in the next section.

Factors that influence the contextual interference effect

Shewokis (1997) and Brady (2004) argued that the acquisition, retention, and transfer of motor skills may be affected by the interaction between task and subject characteristics. Several authors (Barreiros et al., 2007; Landin & Hebert, 1997) have explained the difference between results from laboratory and field-based studies by the fact that, in laboratory studies, many variables can be controlled. Conversely, in ecological studies, it is very difficult to create the optimal conditions needed to generate learning effects such as the CIE. According to Lee and White (1990), the CIE appears in the laboratory because the tasks generally pose few motor demands, are cognitively loaded, lack intrinsic interest, and quickly reach an asymptote.

Now we will describe the main task and subject characteristics that seem to have an effect on the acquisition, retention and transfer of a motor skill. These are said to explain the different results observed in ecological and laboratory experiments.

Task characteristics

Simple versus complex task

The simplicity or complexity of the task seems to influence the probability that the CIE will appear. Let us start by defining what a simple task is and what a complex task is. According to Wulf and Shea (2002), a task is simple if it has only one degree of freedom, which can be mastered in a single practice session, and if the task appears to be artificial. On the other hand, a complex task cannot generally be mastered in a single session, has several degrees of freedom and tends to be ecologically valid. For instance, barrier knock-down tasks, simple aiming tasks, anticipation-timing tasks, and tracking tasks are considered to be simple tasks and all of them have demonstrated the CIE. On the other hand, complex tasks, for which the CIE is less frequently observed than for simple tasks, include, for example, badminton, volleyball and basketball. We should point out that simple tasks are often related to laboratory experiments, while complex tasks are more often related to ecological experiments.

As already mentioned in this review, some theories claim that random practice requires the subjects to engage in deeper cognitive processing (e.g., Brady, 1998; Shea & Zimny, 1988; Smith, 1997) so they can create a more distinctive and complete mnesic representation of the task. Albaret and Thon (1998) claimed that, if the movement to be learned is complex, participants may also have recourse to deeper cognitive processing even if they learn through blocked practice. These authors suggest that the complexity of a task could interfere with the practice schedule and thus could mask the benefits of a random practice. In their study, participants practised a drawing task in which the patterns to be learned differed in terms of the number of segments. Six groups practised three variations of the task: two groups (random and blocked) practised a pattern involving only two segments; two groups (random and blocked) practised three-segment patterns; and the remaining two groups (random and blocked) practised four-segment patterns. The results showed that the random-practice groups got better results than the blocked groups in the transfer tests but only for the two simplest tasks (involving two and three segments). No CIE was found in the transfer task for blocked and random practice groups on the most complex task (four segments). In a series of experiments (Merbah, Lejeune, & Meulemans, submitted) conducted in our laboratory, we failed to obtain the CIE with an inverted-mouse learning paradigm, and attributed this failure to the complexity of the task: because the subjects had to perform each trial as fast as they could in both learning conditions (random vs. blocked), the difficulty of the task was set and maintained at the same level in both conditions. In other words, given the particular constraints of our task, the variability levels of the two learning conditions were similar, and both conditions required deep cognitive processing.

Moreover, the type of variation applied in the learning task can affect its complexity. For example, variations of a task governed by several motor programmes are more complex than variations governed by one motor programme but with parameter modifications (e.g., distance, etc.). However, Magill and Hall (1990) noted that the CIE was much more robust when the tasks were governed by different motor programmes rather than by the same one. The concept of a motor programme is a mnesic representation for a particular class of actions that share certain common or invariant motor control features, such as relative force and timing. Thus, movement production requires selecting the appropriate motor programme and then adding parameters, such as absolute force and duration. Magill and Hall (1990) suggest that practising tasks controlled by different motor programmes rather than the same one results in more interference and consequently more effortful processing for the performer. By contrast, practising tasks governed by the same motor programme requires only parameter modifications, and so the interference is insufficient to generate the CIE.

Many laboratory experiments support Magill and Hall's (1990) proposal (e.g., Gabriele et al., 1989; Giuffrida, Shea, & Fairbrother, 2002; Goodwin & Meeuwsen, 1996; Hall & Magill, 1995; Lee et al., 1992; Wulf & Lee, 1993). On the other hand, some studies obtained a CIE only by changing the task parameters, without changing the motor programme (Sekiya & Magill, 2000; Sekiya, Magill, & Anderson, 1996; Sekiya et al., 1994; Young et al., 1993). However, it seems important to note that the ecological studies present an opposite trend: high contextual interference improves skill learning when there are only parameter modifications (Boyce & Del Rey, 1990; Goode & Magill, 1986; Hall et al., 1994; Wrisberg & Liu, 1991). In other words, for laboratory tasks, the CIE seems more robust when there are variations between several motor programmes whereas, for complex applied tasks, the CIE appears when there are variations within the same motor programme.

In conclusion, we have found that simple tasks generally lead to a CIE, and that, for this reason, the CIE should be larger in laboratory experiments than in ecological experiments. This portion of the review shows an additional element: in laboratory studies, the CIE is larger when learning is based on variations of several motor programmes. On the other hand, the variation of several motor programmes in ecological studies prevents the CIE from appearing. In fact, it seems that an already complex task, which is frequent in ecological studies, becomes too complex if the motor programmes are modified during learning. The opposite seems true of laboratory experiments: the simplicity of that kind of task benefits from the addition of complexity. However, complexity is not only task-dependent but also skill-dependent. A task could be defined as complex for a novice participant but simple for the same participant following a few practice sessions.

Quantity and duration of trials

The amount of training also seems to have an impact on the CIE. According to Shea et al. (1990), the CIE might be negatively influenced by an extended practice session in simple tasks or in blocked practice because subjects may become less attentive and lose their interest. Lee and White (1990) suggest that the CIE might be obtained more easily because most laboratory tasks pose minimal demands on subjects' attention. By contrast, the sports skills used in ecological experiments complicate the production of the CIE. But a random practice schedule could delay inattention and loss of interest and therefore enhance learning; this means that the amount of practice in complex tasks improves the efficacy of the CIE (Sekiya et al., 1996; Shea et al., 1990).

Shea et al. (1990) worked on a blocked or a random practice order where learners received 50, 200, or 400 practice trials on a force production task. After completing 50 trials, the blocked group outperformed the random one but the largest number of trials generated better results for the random group. Thus, this experiment confirmed that a complex task or random practice needs more trials to be learned, whereas a simple task or blocked practice requires fewer trials to be mastered. However, Goodwin et al. (1998), who used a darts task, did not reach the same conclusion: a high number of trials (up to 75) did not improve retention. But one could ask whether we should consider that type of task to be complex or simple.

Other authors emphasise the importance of the duration of the task. First, we must highlight the fact that ecological and laboratory experiments have generally used tasks of relatively short duration such as force production tasks (e.g., Shea et al., 1990), button-barrier tasks (e.g., Lee & Magill, 1983), baseball hitting (e.g., Hall et al., 1994), or golf (e.g., Brady, 1997). For tasks of longer duration, such as bimanual coordination tasks, computer games or rotary pursuit tasks, the CIE does not appear (Heitman & Gilley, 1989; Smith, 1997; Tsutsui et al., 1998; Whitehurst & Del Rey, 1983).

Both the elaboration and reconstruction hypotheses suggest some reasons why shorter trials lead more systematically to the CIE. According to the elaboration hypothesis, a longer practice session reduces inter-task processing, which is progressively replaced by intra-task processing along trials; therefore, the learning advantage related to inter-task processing progressively disappears (Wright, 1991). The reconstruction hypothesis proposes that the reconstruction process diminishes as task duration lengthens. In fact, the action plan would only influence performance directly during the first few seconds of each random trial, after which performance would be based more on ongoing attention to perceptual information. Smith (2002) tested the hypothesis that the CIE would be more pronounced when the training duration is shorter. However, his results did not confirm this assumption. He used the rotary pursuit task and showed that shortening the trial duration actually reduced the effectiveness of random practice, while having no influence on the effectiveness of blocked practice. He tried to explain his unexpected results on the basis of the characteristics and demands of the rotary pursuit task. In fact, this task would be better learned implicitly (Verdolini-Marston & Balota, 1994). However, in a random practice, if the trials are short, there is more inter-task processing and thus more controlled processing; if the rotary task is better learned implicitly, the intervention of controlled processing could impair performance.

Characteristics of subjects

Level of expertise

Magill and Hall (1990) considered a possible interaction between the subjects' level of expertise and the CIE. This link seems logical, as the level of expertise could be correlated with the amount of practice: the more we practise, the more expert we become.

Several studies (Del Rey, 1982, 1989; Guadagnoli, Holcomb, & Weber, 1999; Hall et al., 1994; Hebert, Landin, & Solmon, 1996; Shea et al., 1990) indicate that skill acquisition in novice subjects tends to be higher in low-interference conditions; on the other hand, highly skilled subjects can take advantage of high-interference conditions in both retention and transfer. In a review of current coaching practice in tennis, Guadagnoli (2004) proposed a framework for conceptualising the effects of different practice conditions in motor learning. In his theoretical proposal, they suggest, purely hypothetically, that performance level is linked to task difficulty for subjects with different levels of expertise. He defines difficulty along two dimensions: nominal task difficulty and functional task difficulty. Nominal difficulty refers to a constant level of task difficulty, without taking into consideration who is performing the task or under what conditions; functional task difficulty takes into account the skill level of the subject and the conditions under which the task is being performed. Guadagnoli (2004) suggests that, with a task of a given level of nominal difficulty, an individual at any skill level is likely to perform at a predictable level. For a beginner, performance outcome is expected to be high only under conditions of very low nominal task difficulty. As the task becomes more difficult, the expected level of performance for the beginner drops rapidly; it reaches a floor level of performance at a relatively low level of task difficulty. Expected performance for intermediate and skilled individuals would drop off at moderate rates as a function of increased nominal task difficulty. For the expert, only the most nominally difficult tasks would be expected to pose a problem. In conclusion, if the nominal difficulty increases, performance will decrease and the rate of decline in performance will be more rapid for the lower-skilled performer.

Overall, according to this point of view, both the complexity of the task and the experience of the learner determine the presence of the CIE. When the task is complex (i.e., with high attention, memory, and/or motor demands) or when the learner is relatively inexperienced, random practice may overload the system and its potential benefits could be disrupted.

Learning style

Jelsma and Van Merriënboer (1989) found that an individual's propensity for impulsiveness or reflectivity might influence the CIE. Reflectivity is associated with a tendency to take the time to choose the appropriate solution, while impulsivity refers to the tendency to favour speed instead of accuracy.

Jelsma and Van Merriënboer's (1989) proposal supports two ideas. First, a random condition generates more controlled processing than a blocked condition. This requirement allows a more adequate memory representation for retrieval (Shea & Zimny, 1988). Second, if several possible solutions are present and if it is difficult to determine with certainty which one is the most appropriate, reflective individuals systematically tend to gather information, deploy more attention and make better use of feedback information. In this context, it is expected that reflective subjects would make more intensive use of controlled processing than impulsive ones. Moreover, even under the blocked condition, reflective subjects tend to generate their own contextual interference and then use controlled processing of their own (Shea & Zimny, 1988).

In Jelsma and Van Merriënboer's (1989) study, individuals had to move a cursor quickly and accurately on a computer screen along four different tracks. In the random condition, they performed the four tracks in random order, while in the blocked group, they practised the four tracks in a blocked order. Reflectivity indices were determined by means of a computerized version of the Matching Familiar Figure Test (Van Merriënboer & Jelsma, 1988). Reflective participants appeared to acquire the skill independently of the type of practice schedule. It could be suggested that, unlike impulsive persons, reflective persons use more controlled processing of their own, which makes them relatively indifferent to the effects of random or blocked schedules. On the other hand, results have shown that impulsiveness increases the benefits of random practice. In this context, it could be argued that, in the random condition, subjects tend to decrease their impulsivity and adopt a more reflective style because this condition forces them to make more extensive use of controlled processing.

Anxiety and self-efficacy

Shewokis, Krane, Snow, and Greenleaf (1995, cited by Brady, 1998) suggested that anxiety reduces the benefits of a random schedule because stressed subjects are uncomfortable with variability and unpredicted contexts. However, to our knowledge, this hypothesis has not yet been fully supported by empirical data.

According to Bandura (1997), the notion of self-efficacy – namely, the belief than an individual is capable of executing a certain course of action in order to obtain a specific outcome – could also play a role in the type of practice effect. Highly efficacious individuals adapt more readily to a random schedule, while learning in low-self-efficacy individuals is often accelerated under blocked conditions because the acquisition is quicker and thus is reassuring from the beginning of the task.

Holladay and Quinones (2003) examined the role of 'self-efficacy generality' in the relationship between practice variability and transfer performance. They define self-efficacy generality as the generalisation of the efficacy beliefs associated with one activity to similar ones within the same activity domain or across a range of activities. They conclude that higher practice variability leads to higher self-efficacy generality, demonstrating that performing variations of a task leads individuals to have more similar efficacy beliefs across a wider range of tasks. The improvement in self-efficacy generality produces a higher transfer performance for variations of the task that had not been previously trained.

Clinical relevance

This question of the CIE is also pertinent from a clinical point of view. As mentioned above, in clinical settings, some rehabilitation strategies applied to memory-impaired patients depend on their procedural skills, which may be preserved. Thus, a better comprehension of the optimal conditions in which new procedural skills can be learned should help to develop more efficient rehabilitation programmes. More specifically, the following points will focus on the impact of two diseases on the CIE: Alzheimer's and Parkinson's disease. A group of authors coming mainly from Dick's research team (Dick, Andel, Hsieh, Bricker, Davis, & Dick-Muehlke, 2000a; Dick, Hsieh, Bricker, & Dick-Muehlke, 2003; Dick, Hsieh, Dick-Muehlke, Davis, & Cotman, 2000b; Dick, Shankle, Beth, Dick-Muehlke, Cotman, & Kean, 1996) have studied the CIE in Alzheimer's disease (AD). For example, Dick et al. (2003) administered the rotary pursuit task with three training schedules: constant, blocked, and random. Transfer was assessed using speeds that differed from those practised during acquisition. AD patients and normal elderly subjects receiving constant practice outperformed their peers in the blocked and random conditions during acquisition. Whereas all three types of practice facilitated transfer in the control group, for AD patients, a constant schedule was the most beneficial condition (actually, it was the only condition in which the results improved significantly for both retention and transfer).

We recently carried out a study to investigate the CIE in AD patients through a perceptual procedural task: the mirror-reading paradigm (Merbah, Salmon, & Meulemans, in press). In this task, subjects were told that they would learn to read pseudo-words in a mirror, from right to left. Each trial consisted of presenting three pseudo-words written on a card. The time taken to read all three pseudo-words was measured with a digital stopwatch and recorded for each trial. In the blocked practice, the learning phase consisted of presenting series of pseudo-words constructed with a pre-determined subset of letters from the alphabet (set A), and then presenting pseudo-words constructed with another pre-determined subset of letters (set B); in the random schedule, the pseudo-words were constructed with letters belonging both to set A and set B. The results show that, after the learning phase, the constant group read in the mirror significantly faster than the random group, whose performance did not improve.

The results of these studies might be explained by both the elaboration and reconstruction hypotheses. Both these hypotheses claim that the training schedules have different results because they have recourse to different cognitive resources, since random practice needs more elaborated and controlled processing than the constant version. The hypothesis would be that, in AD, learning is more efficient with a constant schedule because, due to the recurrent aspect of the task, it requires little controlled processing. On the other hand, learning is less efficient in a random schedule because this learning condition calls for elaborative processing and for resources in working memory, flexibility, etc., which are known to be impaired in this pathology.

Dick et al. (2003) also refer to Schmidt's (1975) schema theory to explain their results. This theory claims that the variation in training strengthens a schema that links movement parameters in order to acquire a more flexible ability. Under a constant schedule, AD patients are able to learn a motor skill in the sense that they can develop or access a motor programme, but this works only when the movement to be learned is constant during the acquisition phase. The fact that they do not benefit from random practice tends to demonstrate that they are not able to develop the motor schema needed to successfully acquire a new ability when the environmental constraints are changing. Our own results (Merbah et al., in press) suggest that schema theory applies not only to motor skill learning but to perceptual skill learning as well.

Note that the cortical (and, more particularly, hippocampal) impairment that characterises AD may interfere with patients' capacity to memorise all the necessary data in order to develop a motor programme. Studies of AD patients show that the automatic repetition of a movement in the constant practice blocks may be accomplished without the involvement of the hippocampus. But in that case, the task representation remains inflexible and rigid. So, because of patients' hippocampus deficits, constant schedules may be more efficient than random ones in AD. Motor learning is still possible because the subcortical structures involved in the acquisition of new motor skills are less damaged than the hippocampus. Nevertheless, the learning conditions that allow patients to learn and transfer motor skills may be limited by the cognitive deterioration associated with this pathology. So it would seem that, in this pathology, learning and transfer of a skill remain possible, but only in constant conditions which demand few hippocampal resources. To evaluate this interpretation linked to the hippocampal impairment in AD, future studies will have to determine whether amnesic patients with hippocampal damage show the same pattern of skill learning as AD patients.

The same kind of research has been carried out in Parkinson's disease (Haaland, Harrington, O'Brien, & Hermanowicz, 1997). In this pathology, the ganglia connected to the prefrontal cortex are impaired, which damages motor skill learning. According to Harrington, Haaland, Yeo, and Marder (1990), findings concerning the integrity of procedural memory in Parkinson's disease are contradictory. For instance, there are contradictory results for perceptual and motor tasks (mirror reading vs. rotary pursuit), and even within the same motor task. These observations could mean that the basal ganglia and their interconnections are not essential for all kinds of procedural learning. In order to explore this issue, Haaland et al. (1997) compared two practice schedules: random (high cognitive needs) and blocked (low cognitive needs). They showed that Parkinson's patients learned only in the blocked practice condition. This could be related to the executive deficit caused by the ganglia alteration: because Parkinson's patients show an executive impairment, they do not learn in the random practice condition. In order to confirm that random practice is characterised by significant recourse to executive functioning, the authors administered several executive tests. However, they found no significant correlation between the random schedule and the results in the executive tests. According to the authors, this could be explained either by the fact that their patients were not deficient enough or because their executive testing was not sensitive enough to the patients' executive deficits.

Conclusions

We have seen that the CIE has generally been demonstrated in studies in which laboratory tasks were used. Different theories have attempted to account for the CIE: the elaboration hypothesis, the reconstruction hypothesis, the retroactive inhibition hypothesis, and Schmidt's schema theory. For example, according to both the elaboration and reconstruction explanations, a random schedule is characterised by superior cognitive demands compared to the blocked schedule. The more elaborated processing required by random practice conditions promotes a more efficient retention and transfer of abilities.

On the other hand, the evidence of the CIE is not so clear in field-based studies. Actually, most such studies have failed to show the CIE. Regarding the different theoretical hypotheses that have tried to account for the CIE, none of them explicitly explains the difference between the laboratory and field studies. However, one might consider that the elaboration and reconstruction hypotheses are more able to account for this difference than the other theories. Indeed, only these two theories highlight the fact that the random schedule is characterised by superior cognitive demands compared to the blocked schedule. If one admits that ecological tasks are generally more complex than laboratory tasks, the hypothesis that the random condition is characterised by superior cognitive demands could also explain the different results in the field and laboratory studies. In this view, the random condition in an ecological task could overload the subject's cognitive system and cancel out the benefit of the random over the blocked condition observed in laboratory tasks.

Studies that have attempted to highlight the main differences between laboratory and ecological results have identified two main factors – one related to characteristics of the task itself, the other linked to characteristics of the subjects – that could determine the manifestation of the CIE.

Regarding task characteristics, a notion that has still never been investigated is the effect of retention interval on the CIE. More specifically, to what extent does the CIE exist after longer retention intervals? Many studies of memory functioning have demonstrated the importance of the waiting period between the end of training and the retention test: during this time, the learning material benefits from consolidation processes. Thus, it would be interesting to determine the effect of the retention interval on different practice schedules. To date, no study has investigated this question. Referring to the different theories of the CIE, one could hypothesise that, at least in laboratory tasks, the random condition would lead to better retention than the blocked one, even after long retention intervals. Indeed, the elaboration, reconstruction, and Schmidt's theories all claim that the mnesic trace is better elaborated and stored in the random condition. According to the retroactive inhibition hypothesis (Poto, 1988), long-term retention should also be better after a random practice than after a blocked practice. This hypothesis claims that, in the blocked condition, the longer after the practice session a retention test is administered, the poorer the retention performance. And it should be noted that Albaret and Thon (1998) have shown that a blocked condition gives poorer results than a random condition after 48-hour retention interval compared to an immediate retention test.

Similarly, the inter-trial interval is also an important factor that has been demonstrated to have an effect on learning. Specifically, the superiority of a distributed training schedule over a massed training condition is often mentioned in the literature (Dempster, 1989; Greene, 1989; Sisti, Glass, & Shors, 2007): distributed learning refers to a practice schedule in which periods of training are interspersed with rest periods; massed training refers to a continuous block of training. Consolidation processes are generally considered to account for the superiority of distributed over massed training for learning. According to the reconstruction hypothesis, the longer the inter-trial interval, the more the subject will forget the action plan and have to reconstruct it. So, reconstructing the action plan at each trial generates a better ability to create appropriate responses when the learner is confronted with a new transfer task.

To what extent can the retention interval and inter-trial interval explain the differences between ecological and laboratory studies? Regarding the retention interval, there are no clear differences between laboratory and ecological studies that would allow us to explain the appearance of the CIE. As for the inter-trial interval, no study has clearly investigated the effect of spaced versus massed learning on the CIE. Moreover, when we look at the literature, it is difficult to classify existing studies according to this characteristic because we do not have a clear definition of what spaced or massed distribution is. Indeed, to consider that a particular learning situation corresponds to spaced training, it is necessary to have a pause between the learning blocks. But is a pause of a few minutes really sufficient to claim that the training is spaced? More clarification of these concepts is necessary; maybe further research specifically investigating the effects of retention interval and inter-trial interval on the CIE would explain some of the differences between field and laboratory studies.

Another factor that could be of importance for the CIE is the feedback given to the subject. Although many studies have focused on the impact of feedback on simple and complex learning skills, this factor has been rarely incorporated into studies on the importance of the organisation schedule (blocked or random) for skill learning. In fact, one of the most important variables in the motor-learning process is the feedback provided to the learner attempting to acquire a new motor skill. Wulf and Shea (2002) reviewed the findings related to the frequency of feedback about different task components. The main idea is that, in order to learn a simple ability, it is better to reduce the frequency of feedback and increase the delay. Feedback has a positive effect when it allows subjects to correct their wrong answers. However, too much feedback results in excessive facility in response planning, which reduces the need to perform memory retrieval operations (Wulf & Schmidt, 1994). This observation is not true of more complex tasks, where feedback can be very useful. Apparently, though, a good way to provide feedback is to present it only after a certain number of trials.

Wulf, Shea, and Matschiner (1998, Experiment 2) used a ski simulator task and their conclusion was that, contrary to studies that used simpler tasks in which reducing the relative frequency of feedback was more beneficial for learning, performance on this more complex task was enhanced by 100%

feedback, that is, feedback given after each acquisition trial (for another example of the beneficial effects of frequent feedback for complex motor skill learning, see Swinnen, Lee, Verschueren, Serrien, & Bogaerds, 1997).

This indicates that, on the whole, feedback improves skill learning; however, in order to use feedback in the most efficient way, it must be adapted to the complexity of the task: less feedback for simple tasks, and more for complex ones. Further research is needed to examine the effectiveness of various combinations of feedback frequency and scheduling (blocked vs. random).

Lastly, it has been shown that subjects who present a cognitive decline, such as Alzheimer's and Parkinson's patients, are able to learn a new skill only through constant practice. This probably happens because constant practice is less costly in cognitive resources than random practice. Indeed, even though few studies have been carried out in this field (Dick et al., 2000a; Dick et al., 2003; Dick et al., 2000b; Dick et al., 1996; Haaland et al., 1997; Merbah et al., in press), all of them have demonstrated the superiority of constant practice over random practice in both these pathologies. This observation can be viewed as contradicting the generally acknowledged claim that AD patients present a preserved procedural memory (for a review, see Salmon, 2000). Note, however, that if we analyse the literature in more detail, it appears that this claim is not fully supported (e.g., Rouleau, Salmon, & Vrbancic, 2002). In fact, procedural learning does appear to be preserved in AD, especially in studies that used simple, basic tasks or proposed a certain constancy in the acquisition phase. For example, in research using the rotary pursuit task (Bondi, Kaszniak, Rapcsak, & Butters, 1993; Deweer et al., 1994; Dick, Nielson, Beth, Shankle, & Cotman, 1995; Eslinger & Damasio, 1986; Heindel, Butters, & Salmon, 1988; Heindel, Salmon, Shults, Walicke, & Butters, 1989; Jacobs, Adair, Williamson, Na, Gold, Foundas et al., 1999; Libon, Bogdanoff, Cloud, Skalina, Giovannetti, Gitlin et al., 1998) and showing preserved procedural memory in AD, we note that the task was administered in a repetitive way, without any variation.

Moreover, other elements can modulate the preservation of procedural memory in AD. It appears that many patients were excluded from several studies that concluded that procedural memory is preserved in AD. For example, Hirono, Mori, Ikejiri, Imamura, Shimomura, Ikeda et al. (1997) showed that 11 AD patients out of 20 presented equivalent results to controls on a computerized puzzle task. Knopman and Nissen (1987) proved that AD patients learned the sequence normally in a Serial Reaction Time task; however, we note that 7 patients out of 35 were unable to perform this task. In a similar study, Knopman (1991) also excluded 5 patients out of 16 because of their weak results. Likewise, Gabrieli, Corkin, Mickel, and Growdon (1993) found evidence of preserved procedural learning in AD with a mirror drawing task; however, these authors excluded subjects who were unable to perform the initial task (to draw simple vertical and horizontal lines).

Why were these subjects not able to correctly perform these procedural tasks? Rouleau et al. (2002) investigated this question and tried to replicate Gabrieli et al.'s (1993) results. Their aim was to determine the parameters that made the excluded patients unable to acquire the skill. With this in mind, they administered several executive tests; their results showed that, independently of their general cognitive decline, the excluded patients performed worse on executive tests than the included patients. Thus, it seems that these patients could not learn the mirror tracing skill because this task requires executive components.

In summary, it seems that both Alzheimer's and Parkinson's patients are able to learn new skills, but mainly through constant and repetitive practice. The explanation of the superiority of constant practice over random practice could be the same in both these pathologies: random practice demands more cognitive processing (such as executive processing) than constant practice. Executive processing is generally impaired in these pathologies and this could explain the patients' difficulties learning a skill through random practice. However, further research is needed to examine the effect of scheduling in more detail and to better understand the reasons for the superiority of constant practice in Alzheimer's and Parkinson's diseases, as well as to determine the specific role of executive processes in the random practice situation.

This review of the studies of CIE leads to the conclusion that no universal practice schedule can be applied in every context and for all types of people. In fact, it seems essential to take into consideration the characteristics of the task and of the subjects in order to choose the most appropriate type of practice schedule. For example, motor skills with low demands benefit more from practice conditions that increase the load and challenge the performer. However, the acquisition of skills that place extremely high loads on the performer's cognitive system is likely to be more efficient under conditions that reduce the load to more manageable levels. Of course, it remains to be determined on what basis a task can be defined *a priori* as simple or complex. As we saw, in Wulf and Shea's (2002) view, a task is simple if it has only one degree of freedom, can be mastered in a single practice session, and appears to be artificial. On the other hand, a complex task generally cannot be mastered in a single session, has several degrees of freedom and is likely to be ecologically valid. Unfortunately, these definitions remain inadequate. For example, the subject's level of expertise would need to be considered as well. Complexity is not only task-dependent but also skill-dependent. A task could be defined as complex for a novice participant but simple for the same participant following some practice.

Moreover, Anderson (1992; Anderson, Fincham, & Douglass, 1997) claims that the first steps in procedural learning can be considered to constitute a situation that is loaded in cognitive resources, and so in controlled processing. With practice, controlled processing decreases while the role of automatic processing increases, and performance becomes faster and less prone to conscious control (i.e., more unconscious). From this perspective, learning an overly complex task will add a supplemental cognitive load in the early stages of learning, which already require considerable cognitive resources. This overload can quickly submerge the subject and produce a negative impact on learning. Similarly, even with simpler tasks, subjects with a very poor level of expertise might also be cognitively submerged during the first steps of learning.

In this context, Brady (2008) proposed that future studies of contextual interference should manipulate not only task difficulty but also the contextual continuum (with the blocked and random conditions at both ends of the continuum). In other words, he proposed low contextual interference levels for low-skilled participants, moderate levels for mid-level participants, and high levels for the highly skilled. Indeed, even if there is no one solution, it might be possible to combine the advantages of the two schedules: using a blocked schedule in the early stages of learning would decrease the cognitive load, while the later introduction of a random practice schedule could enhance the subject's mnesic representation, making it more profound and more elaborated. This profound storage would then generate better retention and transfer (see also Prahl & Edwards, 1995).

Nevertheless, future studies will be necessary to test the relevance and effectiveness of such a procedure with different motor skill learning tasks, particularly in the context of rehabilitation programmes designed for memory-impaired patients.

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