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Interactive influence of task characteristics and amount of practice on the contextual interference effect in motor learning: A review

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Abstract: The contextual interference (CI) research related to the Magill and Hall (1990) hypothesis concerning task characteristics was reviewed to reexamine the hypothesis. Through this process, describing the weaknesses of the hypothesis led to proposing a multiple factor approach to the generalizability of the CI effect. A modification to the Magill and Hall hypothesis was proposed considering the interaction between task characteristics and the amount of practice. The modified hypothesis holds that when task variations are controlled by different generalized motor programs (GMPs), the CI effect would be found in both early and later practice. In contrast, when task variations are controlled by the same GMP, the CI effect would be found only in later practice.

Key words: contextual interference (CI), generalized motor program (GMP), amount of practice, motor learning

Introduction

During the last two decades, many motor learning studies have focused on dissociating between temporary performance effects and relatively permanent learning effects. These studies have demonstrated some paradoxical phenomena whereby practice schedules that hinder acquisition performance actually facilitate learning as assessed by retention and transfer tests (See Chamberlin & Lee, 1993; Lee, Swinnen, & Serrien, 1994, for reviews). These phenomena have practical implications for real world motor learning situations because people tend to choose practice schedules that lead to the best performance during practice but have little concern for retention and transfer aspects of skill learning (Bjork, 1994).

One of the paradoxical phenomena is the contextual interference (CI) effect. This effect occurs when multiple tasks or variations of a task are practiced under conditions of high and low levels of CI. Typically, random (high CI) practice, where all tasks are practiced in an unsystematic order, leads to inferior acquisition performance but superior retention and/or transfer performance compared to blocked (low CI) practice, where one task is repeatedly practiced before practice of another task begins. In addition, serial (high CI) practice, where tasks are practiced in a certain order but the same task is not repeated for consecutive trials, also leads to the same effect as random practice has on acquisition,

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retention and transfer (e.g., Lee & Magill, 1983). The CI effect was first found in the motor domain by J. B. Shea and Morgan (1979) and many studies have replicated their findings with a variety of skills, types of learners and experimental procedures (See Chamberlin & Lee, 1993; Magill & Hall, 1990, for reviews).

Although the CI effect is a robust phenomenon in the motor learning literature, previous studies which will be reviewed in the next section suggest that the CI effect is not found in all motor learning situations but its efficacy interacts with characteristics of tasks, subjects and experimental procedures used. However, the influence of each of these characteristics on the CI effect was examined separately from each other and interactive influences were paid little attention. Therefore, the purposes of the present paper are 1) to review the studies on the CI effect from a viewpoint of generalizability of the effect and 2) to propose a hypothesis which considers the interactive influence of more than one factor on the CI effect.

Previous Research on the Contextual Interference Effect

Following J. B. Shea and Morgan's (1979) study, many studies have found the CI effect in motor learning. Those studies can be grouped based on the primary purpose of each study. The first group of studies directly focused on investigating why the CI effect occurs. For example, J. B. Shea and Morgan (1979) explained the CI effect from a viewpoint of levels of elaboration imposed on learners. The elaboration view holds that under high levels of CI during acquisition, information about multiple tasks are simultaneously present in the working memory and more elaboration is required to distinguish one task from the others. This promoted level of elaboration is considered to facilitate learning. This explanation has some empirical support (e.g., Limons & Shea, 1988; J. B. Shea & Zimny, 1988; Wright, 1991; Wright, Li, & Whitacre, 1992).

An alternative explanation has been proposed by Lee and Magill (1985) from a viewpoint of reconstruction of action plans. It states that under high levels of CI, an action plan for a particular task needs to be reconstructed every time that task is performed because the action plan is completely or partially forgotten from the working memory by intervening other tasks. Although this reconstruction process hinders acquisition performance, retention and transfer are enhanced because it is this reconstruction process that is required during retention and transfer tests. The reconstruction view has also been empirically tested and supported by some studies (Lee & Weeks, 1987; Magill, 1988; Meeuwsen & Magill, 1991).

Other groups of studies investigated the generalizability of the effect in a variety of settings. One of these groups included studies that investigated the influence of task characteristics on the CI effect. The CI effect was found with real world motor skills such as volleyball (Bortoli, Robazza, Durigon, & Carra, 1992), rifle shooting (Boyce & Del Rey, 1990), badminton serves (Goode & Magill, 1986; Wrisberg, 1991; Wrisberg & Liu, 1991) and baseball batting (Hall, Domingues, & Cavazos, 1994). These studies provided evidence that the CI effect can occur outside a laboratory. One of other task characteristics investigated concerns cognitive and motor components of skills. Carnahan, Van Eerd, and Allard (1990) proposed that the CI effect occurs only when tasks require generation of overt movements, suggesting that different levels of CI are attributed to the process of learning motor components of a task. However, the CI effect has been found in imagery practice (Gabriele, Hall, & Lee, 1989) and observational learning (Blandin, Proteau, & Allain, 1994) paradigms where only cognitive components of tasks create different levels of CI. Similarity of task variations is another task characteristic that has recently intrigued many researchers following the Magill and Hall (1990) hypothesis. Similarity has been defined in terms of characteristics of generalized motor program (GMP) in their hypothesis and controversial findings have been reported (Hall & Magill, 1995; Lee, Wulf, & Schmidt, 1992; Sekiya, Magill, & Anderson, 1996; Sekiya, Magill, Sidaway, & Anderson, 1994; Wood & Ging, 1991; Wulf, 1992; Wulf & Lee, 1993). Because it is related to the main theme of the present study, it will be discussed in detail in later sections.

The third group includes studies that examined the influence of subject characteristics. One of them is related to skill levels of learners. Although Del Rey (1982) found the CI effect only for subjects who demonstrated a higher proficiency level of performing a task, other studies failed to find the influence of skill levels on the CI effect (Del Rey, Whitehurst, Wughalter, & Barnwell, 1983; Smith & Rudisill, 1993). Another subject characteristic is related to cognitive styles of learners. Jelsma and his colleagues (Jelsma & Pieters, 1989; Jelsma & Van Merrienboer, 1989) investigated the CI effect for subjects who are considered to be either impulsive or reflective. The impulsive subjects are those who respond to stimuli quickly but with less accuracy, while the reflective subjects are those who react slowly but with more accuracy. The results of these studies showed that the CI effect is more likely to occur for reflective subjects than impulsive subjects. In addition, the CI effect has been demonstrated not only for normal population but also for subjects with Down's syndrome (Edwards, Elliott, & Lee, 1986) and mental retardation (Heitman & Gilley, 1989).

The last group of studies addressed the influence of experimental procedures on the CI effect. One of procedural characteristics concerns practice conditions. Al-Ameer and Tool (1993) found that a combination of blocked and random schedules during practice was as effective as a pure random schedule to facilitate learning. However, Pigott and Shapiro (1984), using a younger population of subjects, found that the blocked-random mixed schedule was more effective than either a pure blocked or pure random schedule, suggesting that there may be an interaction between practice conditions and subject characteristics. Extra training after practice is another procedural characteristic that may influence the CI effect. Del Rey (1989) found that extra training on tennis skills facilitated benefits of random practice on a coincident timing task.

Although the influence of augmented feedback, which is another procedural characteristic, on the CI effect has been investigated, Del Rey & Shewokis (1993), Dunham, Lemke, and Moran (1991) and Weir (1988) found no influence of feedback manipulations on the CI effect. The only exception is the study by Wulf (1992) in which reducing the presentation frequency of knowledge of results (KR) facilitated the occurrence of the CI effect. Another and most relevant procedural characteristic to the present review is the amount of practice. Although C. H. Shea, Kohl and Indermill (1990) found that the amount of practice is a factor that influences the efficacy of the CI effect, Proteau, Blandin, Alain and Dorion (1994) found no influence of the amount of practice. However, because task variations used in these studies can be contrasted from a viewpoint of underlying GMP structures, these inconsistent findings will be discussed with regard to the interactive influence of the amount of practice and GMP characteristics in later sections.

Taken together, although the CI effect has been found with a variety of tasks, subjects and experimental procedures, there were some occasions in which the CI effect was not found. Investigation of the generalizability of the CI effect has been approached separately from either task, subject or procedural characteristics, as the studies could be grouped based on which factor researchers were interested in. However, the influence of multiple factors and interactions among them have rarely been investigated.

The Magill and Hall (1990) Hypothesis

One of the single factor approaches was taken from the viewpoint of task characteristics and it is well represented as the hypothesis proposed by Magill and Hall (1990). They proposed a limitation to the generalizability of the CI effect with respect to underlying GMP structures of task variations to be learned. Although the hypothesis has been examined by many studies, findings were inconsistent among those studies (e.g., Lee et al., 1992; Sekiya, et al., 1994). Therefore, in this section, the Magill and Hall hypothesis and a rationale for it will be presented followed by the findings of studies that examined the hypothesis.

The Magill and Hall (1990) hypothesis holds that the CI effect would be found when task variations to be learned are governed by different GMPs, but should not be found when task variations are governed by the same GMP. The GMP is a hypothetical notion for a memory representation that governs a class of movements (Schmidt, 1975, 1985, 1988). The GMP has invariant features such as relative timing and relative force and variant features such as overall duration and overall force. The invariant features refer to compositional relationships of time and force among movement components and are the fundamental structures of the GMP. The variant features are parameters added to the fundamental GMP structures and scaling of movements can be performed by modifying parameters of the GMP. Under this conceptualization, task variations with different invariant and variant features belong to different movement classes and are controlled by different GMPs. On the other hand, when task variations share the same invariant features but differ only in variant features, the task variations belong to the same movement class and are controlled by the same GMP. For example, three different tennis strokes, such as a serve, a forehand ground stroke and a backhand ground stroke, are controlled by three different GMPs, while hitting a serve with different amounts of force requires parameter modifications of the same GMP. According to the hypothesis, the CI effect is unlikely to occur when task variations from the same GMP are learned.

A rationale for the hypothesis

The Magill and Hall (1990) hypothesis was based on the reconstruction hypothesis proposed by Lee and Magill (1983, 1985) to explain the mechanism of the CI effect. Lee and Magill suggested that when several tasks are practiced under a high CI condition, action plans for each task need to be reconstructed every time they are performed because forgetting occurs due to the intervention of other tasks. In contrast, when one task is practiced consecutively under a low CI condition without the intervention of other tasks, an action plan for the task can be used without reconstruction. Thus, the reconstruction process under the high CI conditions hinders acquisition performance. However, this more effortful information processing mode leads to enhance memory representations that are measured as retention and transfer performance.

Because the action plan consists of a fundamental GMP structure and parameters added to it, action plan reconstruction consists of GMP construction and parameter modifications (Magill & Hall, 1990). When task variations controlled by different GMPs are practiced under high CI conditions, both GMP construction and parameter modifications are necessary from one performance to another. This complete reconstruction of the action plan under high CI practice requires more effortful processing than under low CI. Therefore, the CI effect is found with task variations controlled by different GMPs. In contrast, when task variations controlled by the same GMP are practiced under high CI conditions, only parameter modifications are necessary from trial to trial, leading to minor interference that is similar to one created under low CI conditions. Because this minor interference does not lead to effortful processing, no CI effect is expected to occur when task variations share the same GMP structure.

Tests of the Magill and Hall (1990) Hypothesis

Studies that support the Magill and Hall (1990) hypothesis

The Magill and Hall (1990) hypothesis is indirectly supported by studies that found no CI effect with task variations controlled by the same GMP. When variations of a pursuit rotor task with different movement speeds were learned, no CI effect was found (Heitman & Gilley, 1989; Whitehurst & Del Rey, 1983). Variations of a linear positioning task with different movement distances also revealed no CI effect (Turnbull & Dickinson, 1986). In addition, Wulf (1992) had subjects practice moving a lever by hand to reproduce goal spatio-temporal movement patterns that required modifications of the overall force parameter of the same GMP. The results of this study supported the Magill and Hall hypothesis as the CI effect was not found for task variations controlled by the same GMP unless frequency of KR presentation was reduced to promote the level of processing.

Wulf and Lee (1993) also examined the Magill and Hall (1990) hypothesis using a data analysis technique that enabled them to dissociate performance measures related to parameter learning from performance measures related to GMP learning. They had subjects practice hitting four buttons so that movement times (MTs) for each segment match goal MTs for each segment. The task variations learned had goal MTs in the same relative timing composition, but the variations differed only in total MTs. Thus, these task variations required modifications of the overall duration parameter of the same GMP. With the dissociation measurement technique, parameter learning was assessed based on differences between the goal total MTs and observed total MTs, while GMP learning was assessed based on differences between the goal relative timing and observed relative timing. The significance of using this dissociation measurement technique is that the rationale for the Magill and Hall hypothesis that parameter modifications do not create sufficient interference to produce the CI effect can be directly examined. In the previous study that used the similar task variations (Lee et al., 1992), only a general performance measure that reflects both GMP learning and parameter learning together was used, making the direct examination of the rationale for the hypothesis impossible. The results of Wulf and Lee's study showed that, in support of the Magill and Hall hypothesis, no CI effect was found for the measure of parameter learning in both retention and transfer.

Although these findings described above are consistent with the prediction of the Magill and Hall (1990) hypothesis, none of these studies compared task variations from different GMPs with task variations from the same GMP. To attribute the lack of the CI effect solely to the task characteristics, it is necessary to involve both types of task variations within an experiment. This approach was used by Wood and Ging (1991). They used task variations with high and low similarity within a study to investigate the influence of the task characteristics. One set of task variations required subjects to knock down small barriers with one hand in different spatial configurations. The other set of task variations had barriers in a similar shape pattern but with different sizes. However, the nature of these task variations and the data analysis techniques had two inherent problems to support the Magill and Hall hypothesis.

First, as the authors also pointed out in their discussion, the high similarity task variations did not share the same relative timing structure. Thus, the task variations can not be considered to be controlled by the same GMP. Second, their conclusion that the CI effect was found only for low similarity task variations was derived based on the analysis of performance transition from acquisition to retention. This analysis confounded performance effects and learning effects. When the absolute performances in retention and transfer were analyzed, no CI effect was found for either the high or low similarity task variations. Therefore, although this study has been cited as a source of a support for the Magill and Hall hypothesis (Chamberlin & Lee, 1993; Magill, 1992, 1993; Magill & Hall, 1990), it does not provide strong support for the Magill and Hall hypothesis.

Another within-study approach was used by Lee et al. (1992). They had subjects practice variations of a sequential tapping task that had either the same or different relative timing structures. Although the retention results showed no CI effect regardless of the task characteristics, the transfer results showed the CI effect only for the different GMP task variations but not for the same GMP task variations. Thus, this study provided a partial support for the Magill and Hall (1990) hypothesis.

Studies that do not support the Magill and Hall (1990) hypothesis

Although the results of the studies described above are consistent with the prediction derived from the Magill and Hall (1990) hypothesis, some recent studies found the CI effect with task variations that are considered to be controlled by the same GMP. The CI effect was found when Carnahan et al. (1990) had subjects practice variations of a timing task that required modifications of the overall duration parameter of the same GMP. In another study by C. H. Shea et al. (1990), subjects learned variations of a rapid force production task that required modifications of the overall force parameter of the same GMP. The results showed the CI effect when the amount of practice was increased. Young, Cohen, & Husak (1993), using variations of a rapid aiming task with similar movement patterns, found the CI effect. In addition, Hall et al. (1994) had skilled baseball players practice hitting fastballs, curveballs and change-ups. Although the movements to hit these types of pitches are very similar and they are considered to be governed by the same GMP, the results of this study showed a CI effect. These findings are inconsistent with the Magill and Hall hypothesis that predicts no CI effect with this type of task variation.

Sekiya et al. (1994) more directly examined the hypothesis by combining the experimental procedures used by Lee et al. (1992) and Wulf and Lee (1993). In this study, task variations controlled by either the same or different GMPs, which were similar to that used by Lee et al., were practiced in either a high or low CI condition. In data analysis, in addition to a general performance measure, GMP learning and parameter learning were assessed separately using a dissociation measurement approach similar to that used by Wulf and Lee. The results of the general performance measure revealed the CI effect regardless of the task characteristics, contrary to the Magill and Hall (1990) hypothesis. When the dissociated measures of GMP learning and parameter learning were examined, further evidence was found against the Magill and Hall's rationale for the hypothesis that parameter modifications do not create sufficient interference to produce the CI effect. With the task variations from the same GMP, the measure of parameter learning revealed a clear CI effect, suggesting that parameter modifications can create sufficient interference to facilitate learning contrary to the rationale of the hypothesis.

Furthermore, these findings by Sekiya et al. (1994) with modifications of the overall duration parameter were replicated in the study by Sekiya et al. (1996) with modifications of the overall force parameter. In this study, subjects practiced moving a computer mouse along a linear track to reproduce goal spatio-temporal movement patterns that required modifications of the overall force parameter of the same GMP. The results showed that the CI effect was found for a general performance measure as well as for a measure of parameter learning. This study provided further evidence that parameter modifications of the same GMP lead to effortful information processing under high CI practice to subsequently facilitate learning.

Additionally, another evidence against the Magill and Hall hypothesis (1990) can be seen in the results of the study by Hall and Magill (1995). They used task variations from both the same and different GMPs within a study as it was the case in the studies by Lee et al. (1992) and Sekiya et al. (1994). In this study, many different types of retention and transfer tests were used. The results showed that the CI effect was found in some of the tests regardless of the GMP characteristics of the task variations. Therefore, both types of task variations produced the CI effect.

Generalized Motor Program Characteristics and Amount of Practice

Although there are many studies that support or do not support the Magill and Hall (1990) hypothesis, the fact that the CI effect was found in many studies that used task variations controlled by the same GMP suggests that this type of task variation can produce the CI effect under some conditions. It is therefore questionable that the same vs. different GMP contrast is such a powerful single factor that determines the occurrence of the CI effect. Rather, it is possible that the GMP characteristics interacts with other characteristics such as subjects and experimental procedures.

One possible interaction is the interaction between the GMP characteristics and the amount of practice. The Magill and Hall (1990) hypothesis concerning only the GMP characteristics could be extended by considering the influence of the amount of practice on the CI effect. Because the amount of practice is directly related to stages of learning (Magill, 1993), understanding characteristics of stages of learning in terms of different task demands required on each stage would help understand why the amount of practice and GMP characteristics interactively influence the CI effect. Because several models have been proposed to identify different characteristics of stages of motor learning, those models will be briefly described before the interactive influence of the amount of practice and the GMP characteristics is discussed.

Stages of motor learning

There are three models proposed to identify stages of learning. Fitts (1964; Fitts & Posner, 1967) identified three stages of motor learning. In the first stage, called the cognitive phase, a learner tries to understand the goal of the task and what needs to be done to achieve the goal. This stage is also characterized by a large variability in movements because different movements result from a variety of strategies used by the learner. In the second stage, called the associative phase, the learner develops appropriate movement patterns to perform the task. As the movement patterns become stable, fine adjustments are made to reduce the variability in movements. In the last stage, called the autonomous phase, the learner reduces attention demand imposed by the task and becomes capable of doing other tasks simultaneously.

Although Adams (1971) identified only two stages of motor learning, the first stage, which was labeled the verbal-motor stage, has the similar characteristics as the first two stages proposed by Fitts (1964; Fitts & Posner, 1967). The second stage was termed the motor stage and the learner in this stage can perform consistently because an error detection mechanism has already been developed. Because conscious awareness of what needs to be performed is minimum in this stage, it is similar to the autonomous phase proposed by Fitts. Although only two stages were identified by Adams, his model essentially involves all characteristics proposed by Fitts.

The third model proposed by Gentile (1972) also identified only two stages of learning. The first stage is characterized as the period of getting the idea of the movement. In this stage, two aspects are emphasized. First, the learner dissociate relevant stimuli from non-relevant stimuli in the environment. Second, the learner develops coordinated movement patterns that are appropriate for achieving the goal of the task. In contrast to the first two models proposed by Fitts (1964; Fitts & Posner, 1967) and Adams (1971), the second stage proposed by Gentile has two distinct characteristics depending on the nature of the task. When a closed motor skill, where the environment does not change during a trial or from trial to trial, is to be learned, the main goal is to refine the movement that was already developed in the first stage. This process was called fixation. On the other hand, when the task to be learned is an open motor skill, where the environment changes during a trial or from trial to trial, diversification is the primary goal. The diversification refers to process of increasing movement repertoire in order to adapt to the changing environment.

Although the three models described above have different numbers of stages and different labels for the stages, some commonalties exist among them. First, all of the models emphasize the importance of cognitive demand in early practice and it decreases as practice progresses. Second, all of the models maintain that in early practice the learner searches the most appropriate movement pattern from a variety of possible movement patterns. This is then followed by refining and stabilizing the selected movement pattern in later practice. This transition from acquisition of fundamental movement patterns to refinement of them is consistent with the hierarchical organization of the movement proposed by some motor learning theorists. According to Kugler, Kelso, and Turvey (1980) and Newell (1985), the most appropriate movement pattern is selected through the process of acquisition of coordination, which is defined as topological relationships in the body and limbs. Refinement of the movement is achieved by control of the movement, which is defined as scaling of movement parameters. Because control of the movement is achieved on the basis of acquisition of coordination, the coordinated movement pattern is established in the early stage of learning and the further practice leads to control of the movement. This hierarchical organization of coordination and control is consistent with the features that all of the models of learning stages have in common.

Although another hierarchical organization of the movement was proposed by Schmidt (1988), it is essentially the same as the hierarchy proposed by Kugler et al. (1980) and Newell (1985). According to Schmidt, coordinated movement patterns are characterized as invariant features of the GMP, such as relative timing and relative amount of force. Thus, acquisition of coordination is synonymous with development of the appropriate GMP structure. On the other hand, refinement of the movement is the process of adding the appropriate parameters, such as overall movement duration and overall amount of force, to the already developed coordinated movement pattern. Therefore, modifications of parameters are achieved on the basis of developing the fundamental GMP structure. Although terms used by Schmidt are different from those used by Kugler et al. and Newell, they essentially refer to the same hierarchical structure that is incorporated in the models of learning stages.

Therefore, for the purpose of examining the interactive influence of GMP characteristics and the amount of practice on the CI effect, two stages of learning are identified in the present paper. In the first stage, the learner develops fundamental movement patterns that have been labeled coordination or GMP. Also, this stage is characterized by emphasized cognitive demands to search for the most appropriate movement patterns. In the second stage, the learner refines the selected movement patterns by adding parameters. Less cognitive demands are imposed on the learner in this stage of learning and movements are produced relatively automatically compared to the first stage. Although distinct characteristics for these stages are identified, transition from one stage to the other occurs gradually along a continuum of the amount of practice.

When the CI effect is associated with these stages of learning, the locus of CI in each stage of learning can be predicted. Because the learner develops the fundamental GMP structure in early practice, this process of searching the most appropriate movement pattern would be the locus of the CI effect in this stage. In contrast, parameter modifications become the primary task demand imposed on the learner in later practice, suggesting that the locus of the CI would be the process of parameter modifications in the later stage. In other words, GMP learning is the source of different levels of CI in early practice, while parameter learning is the source of different levels of CI in later practice. In the following sections, this possible interaction will be discussed based on empirical findings to provide a more appropriate framework for the generalizability of the CI effect.

Influence of practice amount on learning tasks from the same generalized motor program

A good example of the influence of the amount of practice on the CI effect for learning task variations from the same GMP can be seen in the study by C. H. Shea et al. (1990) in which three different amounts of practice were used. They had subjects practice variations of a ballistic force production task with different amounts of force. Thus, these task variations required modifications of the overall force parameter of the same GMP. The task variations were practiced in either a blocked or random context for either 50, 200, or 400 trials. One day after acquisition, retention performance was measured in either a blocked or random context. The results of the retention test showed that after 50 acquisition trials no CI effect was found. In contrast, after 400 acquisition trials a clear CI effect was found in both retention test contexts. After 200 trials, a somewhat moderate effect was found as the random group performed better than the blocked group only in the random retention context. This study demonstrated that the efficacy of the CI effect improved as the amount of practice increased.

When this finding is related to the hierarchical structure of the movement organization, the interaction between the GMP characteristics and the amount of practice becomes clearer. Along the continuum of the amount of practice, the fundamental structures of the movement, such as relative timing and relative force, are developed before specific details of movements, such as overall duration and overall force, are refined. In the other words, for the learner in early practice GMP learning is more demanding than parameter learning, while in later practice parameter learning is more demanding than GMP learning. When task variations from the same GMP are to be learned, the learner in early practice focuses on the fundamental GMP structure regardless of practice contexts. Although the task variations differ in the parameters added to the GMP, the learner in early practice tends to ignore the specific details of the movement. Therefore, in early practice a potential source of different levels of CI is not actively processed by the learner. Because the learner focuses on the fundamental GMP structure that is identical among task variations from the same GMP, little difference is created in information processing under high and low CI practice.

However, with further practice learner's attention shifts from the fundamental GMP structure to more specific details of the movement. Thus, in later practice the learner focuses on modifications of the parameters. Because modifications of the parameters are demanded in later practice, practice schedules with different levels of CI invoke different information processing modes in this stage of learning. Under low CI schedules, such as the blocked practice, parameters of the same GMP do not have to be modified but simply repeated from trial to trial. In contrast, under high CI schedules, such as the random or serial practice, parameters need to be modified from trial to trial due to the changing task demands. Therefore, the difference in the information processing modes under the high and low CI schedules becomes evident only after a sufficient amount of practice is administered. Although these predictions are consistent with the findings by C. H. Shea et al. (1990) in which the influence of the amount practice was manipulated within an experiment, more evidence to support these predictions based on between-study comparisons will be discussed next.

When the inconsistent findings with task variations controlled by the same GMP are reviewed in the light of the amount of practice, it is likely that the CI effect would not be found in studies with a relatively small number of acquisition trials, while the effect would be found in studies with a relatively large number of acquisition trials. The number of trials greater than 200 have consistently produced the CI effect, while many studies with the number of trials less than 150 have failed to find the CI effect. Studies with the number of trials between 150 and 200 have reported inconsistent findings. Although these numbers are presented as a reference for reviewing the studies, exact number of trials to distinguish relatively small and large amount of practice is not important, because the comparisons are made between studies that have a variety of task, subject and procedural characteristics. Rather, a more important aspect that should be derived from the between-study comparisons is a general tendency toward the increased possibility of finding the CI effect as a function of the amount of practice.

For example, variations of a pursuit rotor task with only 15 (Heitman & Gilley; 1989) or 50 acquisition trials (Whitehurst & Del Rey, 1983) and variations of a linear positioning task with only 15 acquisition trials (Turnbull & Dickinson, 1986) have revealed no CI effect. Also, when subjects practiced producing goal spatio-temporal movement patterns that differed only in the amount of overall force with 90 acquisition trials, no CI effect was found unless the frequency of KR presentation was manipulated (Wulf, 1992). In another study by Wulf and Lee (1993), subjects practiced variations of a timing tapping task for 108 trials, but no CI effect was found except for a delayed transfer test with one of the dependent measures used. Although this study provided a partial support for the Magill and Hall (1990) hypothesis, similar task variations practiced for 90 and 180 acquisition trials revealed no CI effect (Lee et al., 1992).

In contrast, the CI effect has been found when task variation governed by the same GMP were practiced with a relatively large number of acquisition trials. In the studies by Hall and Magill (1995) and Sekiya et al. (1994), subjects practiced variations of a timing tapping task that were very similar to those used by Lee et al. (1992) and Wulf and Lee (1993). However, the number of acquisition trials was increased to 198 in Hall and Magill's study and 270 in Sekiya et al.'s study. The CI effect was found with the same GMP task variations in both studies, contrary to the Magill and Hall (1990) hypothesis. In another study by Sekiya et al. (1996), subjects practiced task variations requiring modifications of the overall force parameter for a total of 540 acquisition trials. The results showed a reliable CI effect as it was evident after both 270 and 540 acquisition trials.

In addition, Young et al. (1993) had subjects practice variations of a rapid aiming task for 192 acquisition trials and found the CI effect. Therefore, when task variations share the same GMP structure, there exist a tendency toward that the possibility of finding the CI effect increases as the amount of practice increases. The only exception is the study by Carnahan et al. (1990). In this study, subjects learned knocking down a barrier by one hand in three MTs. Although variations of this timing task required modifications of the overall duration parameter of the same GMP, the CI effect was found after only 60 acquisition trials. One possibility for finding the CI effect with this small number of trials is that the movement required to perform this task was so simple that development of a coordinated movement pattern was achieved with only a few trials. It is therefore suggested that because subjects were involved in the process of parameter modifications from the beginning of practice, different levels of CI were created with this relatively small amount of practice.

Although the studies described above used tasks that were new to subjects, an well learned skill that require only parameter modifications of the GMP in a later stage of learning has also been studied. Hall et al. (1994) had skilled baseball players practice hitting different types of pitches. Because the subjects had years of experience of this skill, they are considered to be in the later stage of learning in which parameter modifications are the primary task demand. Because the CI effect was found in this study, it provides further evidence to support that the parameter modifications of the same GMP creates the CI effect even after an extensive amount of practice.

Influence of practice amount on learning tasks from different generalized motor programs

In contrast to the findings with task variations controlled by the same GMP, there is no evidence that the amount of practice interacts with the efficacy of the CI effect when task variations are controlled by different GMPs. Proteau et al. (1994) investigated the influence of the amount of practice using three different amounts of practice within a study. Because subjects learned knocking down barriers in different spatial patterns, variations of this task were governed by different GMPs. The results revealed that the CI effect was equally found after 54, 108 and 216 acquisition trials, indicating no influence of the amount of practice.

The between-study comparison also suggests no evidence that the amount of practice influences the CI effect when task variations from different GMPs are learned. Although most of the studies with this type of task variations used a relatively small number of acquisition trials, the CI effect was found in many studies. For example, variations of a barrier knockdown task produced the CI effect after 54 trials (Al-Ameer & Toole, 1993; Del Rey, Liu & Simpson, 1994; Lee & Magill, 1983; Limons & Shea, 1988; J. B. Shea & Morgan, 1979; J. B. Shea & Titzer, 1993; Wright, Li & Whitacre, 1992) and 60 trials (Lee, Magill & Weeks, 1985). With a similar task that required hitting buttons instead of barriers in different spatial patterns, the CI effect was found after 135 acquisition trials (Meeuwsen & Magill, 1991; Experiment 3). In the studies where variations of a tapping task had different relative timing structures, the CI effect was found after 198 trials (Hall & Magill, 1995) and 270 trials (Sekiya et al., 1994). When Goode and Magill (1986) had subjects practice three types of badminton serves for the relatively large number of 324 trials, the CI effect was found. The CI effect with two types of badminton serves was also found when the number of acquisition trials was 90 (Wrisberg & Liu, 1991) and 216 (Wrisberg, 1991).

This between-study comparison and Proteau et al.'s (1994) within-study comparison provide no evidence for the influence of the amount of practice on the CI effect when task variations are governed by different GMPs. It is worth noting that, in contrast to task variations governed by the same GMP, task variations governed by different GMPs consistently produced the CI effect with a relatively small number of acquisition trials. This is also explained in terms of the hierarchical structure of motor learning. In early practice, a learner tries to develop the fundamental GMP structure, such as relative timing and relative force. When task variations that have different relative timing or different relative force are learned, the learner needs to develop distinct GMP structures in the early stage of learning. Under high CI practice, such as random and serial practice, this type of task variations impose different task demands on the learner from one performance to another. In contrast, under low CI schedules, such as blocked practice, the same task demand is repeatedly required except when the task is changed from one block to another. Therefore, this type of task variations invokes different information processing modes under different levels of CI in early practice. The more elaborated information processing of the GMP structure under high CI practice is detrimental for acquisition but beneficial for retention and transfer. This suggests that the CI effect occurs even in early practice when task variations are from different GMPs.

On the other hand, if practice of this type of task variations progresses further, the learner's attention shifts from the fundamental GMP structures to scaling of parameters. Under high CI practice, parameters added to the GMPs need to be modified from trial to trial because reconstruction of the GMP structures leads to modifications of parameters that are specific to each GMP. In contrast, under low CI practice, reconstruction of the GMP is not necessary from trial to trial because task demands do not vary except for when tasks are changed between blocks. If the GMP is not changed from one trial to another, parameters that are specific to the GMP are not modified, too. Therefore, practicing this type of task variations under the high and low CI schedules in later practice imposes differential processing modes in parameter modifications. This suggests that the CI effect should be found with task variations controlled by different GMPs even when a relatively large amount of practice is administered.

Conclusion and Suggestions for Future Research

In summary, a modification to the Magill and Hall (1990) hypothesis is proposed. The modified hypothesis involves the interaction between the GMP characteristics and the amount of practice. When task variations are controlled by the same GMP, the CI effect is expected to occur only after a relatively large amount of practice. This type of task variations has only parameter modifications as a source of different processing modes created by different levels of CI. However, because this potential source of different processing modes is not processed by the learner in early practice, no CI is expected to occur at this stage of learning. In contrast, when task variations controlled by different GMPs are learned, the CI effect can be found in both early and later practice. With this type of task variations, both GMP construction and parameter modifications are sources of different processing modes. The high and low CI practice schedules lead to different processing modes in GMP learning in early practice and in parameter learning in later practice.

However, because this modified hypothesis was derived based on comparisons of the studies with a variety of task, subject and procedural characteristics, a more direct examination of the hypothesis needs to be done by manipulating task characteristics and the amount of practice within a study. A possible test of this hypothesis would include four groups of subjects that are combinations of two types of task characteristics and two levels of CI. The first two groups would practice task variations from different GMPs, with one group having a low level of CI and the other group having a high level of CI. The remaining two groups would be exposed to task variations from the same GMP, with one of them having a low level of CI and the other having a high level of CI. Then groups with high and low CI practice schedules for each type of task characteristic can be compared after different amounts of practice. If the present hypothesis is valid, then increasing the amount of practice should increase the likelihood of finding the CI effect for the groups that learn task variations from the same GMP. For the other groups with task variations from different GMPs, however, the CI effect should be found regardless of the amount of practice.

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