CONTEXTUAL INTERFERENCE IN LEARNING NEW PATTERNS OF BIMANUAL COORDINATION

ABSTRACT. Two experiments are reported in which the question of whether or not contextual interference effects are found in motor tasks that require the acquisition of new coordination patterns was examined. Participants (N = 18, Experiment 1; N = 12, Experiment 2) practiced 3 novel bimanual patterns (45 Degrees, 90 Degrees, and 135 Degrees relative phase) in either a random or a blocked order. No statistically significant acquisition or retention differences between groups were found when all 3 patterns were practiced on each of 2 days (Experiment 1). When the blocked group practiced 1 pattern on each of 3 acquisition days (Experiment 2), however, typical contextual interference effects were found: The blocked group performed better than the random group in practice, but the random group performed better than the blocked group in a delayed (by 1 week) retention test. The experiments revealed that contextual interference effects can arise in motor tasks that require the acquisition of new coordination patterns and are not limited to tasks involving novel scaling of a previously existing pattern.

Key words: bimanual coordination, contextual interference, learning, retention

Retention and transfer of motor tasks that have been practiced in a random trial order are usually better than the retention and transfer of tasks that have been practiced in a blocked trial order. That finding, which has been termed the contextual interference effect, has gained research interest in part because of the paradox that performance during the practice period is usually better for blocked than for random practice orders (Shea & Morgan, 1979; for a review, see Magill & Hall, 1990). The implication that temporary performance gains should be sacrificed for long-term benefits in learning represents a fundamental theoretical and practical issue in motor learning.

The existence of contextual interference effects presents both a theoretical challenge (Lee & Magill, 1983, 1985; Shea & Zimny, 1983, 1988) and an important practical consideration for instructors of sport, military, and industrial skills and for rehabilitation therapists (Magill, 1993; Schmidt & Bjork, 1992; Winstein, 1991). Newell and McDonald (1992) have cautioned, however, against zealousness concerning the interpretations of those effects because in much of the research on that issue very simple tasks have been studied.

Two issues in particular have been noted in relation to the use of simple tasks. The first is that in many of the laboratory experiments on contextual interference, the movements to be learned required a new scaling of a previously acquired coordination capability. For example, in studies of movement timing, subjects often had to complete a movement sequence (e.g., one or more aimed arm movements) to spatial targets (e.g., Lee, Magill, & Weeks, 1985). The subjects were capable of performing that movement pattern prior to practice--the motor component to be learned had to be timed so that the movement was completed as closely as possible to a goal duration. Thus, the learner was neither a true novice at the task nor an expert. The theoretical and practical implications of such studies are, therefore, unclear (Newell & McDonald, 1992).

The second issue is that even in studies in which new coordination patterns may be learned, the analysis of movement has been focused on measures of movement outcome. In the example given above, the measure of performance was subjective time estimation relative to an experimenter-defined goal. There were no constraints regarding how the limb produced the movement or in the timing of the subcomponents of the task. That argument also applies to the field studies of contextual interference that have been conducted, in which researchers have used measures of movement outcome as the dependent variables. For example, contextual interference effects in badminton serving (e.g., Goode & Magill, 1986; Wrisberg & Liu, 1991), rifle shooting (Boyce & Del Rey, 1990), and baseball batting (Hall, Domingues, & Cavazos, 1994) have been examined in terms of changes in the end result of the movement, although those changes might not necessarily reflect the changes in patterns of coordination that produced those outcome changes. Thus, in the studies performed to date, random practice has not clearly been shown to result in a long-term change in movement coordination patterns (but see McNevin, 1995).

Our purpose in the present investigation was to examine whether or not contextual interference effects are observed when the task to be learned involves the acquisition and retention of new motor patterns. For two key reasons, we chose a bimanual coordination task as a suitable task with which to address that purpose. First, in considerable research in the past two decades, investigators have used measures of relative phase as global descriptors of bimanual coordination capabilities. Thus, relative phase represents a quantifiable measure of how coordination performance changes during practice. Second, it is known that without practice, only two coordination patterns can be performed skillfully (0 Degress and 180 Degrees relative phase, or in-phase and antiphase). Given sufficient practice and feedback (Swinnen, Lee, Verschueren, & Serrien, 1997), however, subjects are able to learn patterns of bimanual coordination that require a relative phase in between the 0 Degrees and 180 Degrees patterns (i.e., at 45 Degrees, 90 Degrees, and 135 Degrees relative phase; Fontaine, Lee, & Swinnen, 1997; Lee, Swinnen, & Verschueren, 1995; Zanone & Kelso, 1992). Thus, the bimanual coordination task gives one an opportunity to examine the acquisition of three fundamentally new patterns of motor coordination (45 Degrees, 90 Degrees, or 135 Degrees) for which the primary assessment of performance (relative phase) provides a kinematic measure of success in achieving those goal patterns.

EXPERIMENT 1

In this experiment, students in blocked and random groups practiced the three bimanual coordination patterns (45 Degrees, 90 Degrees, and 135 Degrees) for 45 trials on each of 2 days. Retention of those patterns was assessed after 1 week of no practice.

Method

Participants

The participants were 18 volunteer students in the Kinesiology Department at McMaster University, who were awarded course credit for their participation. They were right-handed and between 18 and 24 years of age. The students were randomly assigned to either a blocked group or a random group (with the restriction of equal sample size).

Task

The task was to move both upper limbs from side to side so that three bimanual coordination patterns could be produced. The students grasped two handles that moved in parallel along a trackway on the table. The movements required to achieve the three patterns were continuous back-and-forth movements of both upper limbs whereby the right limb led the left limb by either 1/8 of a complete cycle (458 relative phase), 1/4 of a complete cycle (90 Degrees relative phase), or 3/8 of a complete cycle (135 Degrees relative phase).

Apparatus

The participants sat in a height-adjustable chair, with the center of their bodies in line with the center of the apparatus. Two slide carriages, housed with four sets of ball bearings, ran on top of four parallel steel rods. To move the apparatus, the participants were required to grasp dowel handles, which were positioned 17 cm away from the midline of the apparatus. While grasping the dowels, the participants moved their forearms in parallel, with their elbows flexed. We attached strips of paper along the base of the apparatus to clarify the amplitude goals of the movements (15.5 cm). We connected linear potentiometers (Duncan Electronics, DEL Elec, 612R12KL.08) in parallel to the slide apparatus to encode information, which was sent to an 80486 computer by means of an A-D converter. The participants were required to move at a speed of 1 Hz to perform one complete cycle in time with an auditory metronome (Lafayette Instrument Co. 58025). The LabWindows software program (National Instruments Corporation, version 2.2.1) controlled the start and end of each trial, recorded the positioning data at 200 Hz, and provided visual augmented feedback.

Procedure

The procedures for learning new bimanual coordination patterns followed closely those procedures that we have used successfully in past experiments (e.g., Lee et al., 1995). The participants were given instructions that described the purpose of the experiment and how to produce the three movement patterns (45 Degrees, 90 Degrees, and 135 Degrees relative phase). They were allowed to familiarize themselves with the apparatus while the experimenter orally described the instructions.

As the participants performed each trial, only vision of their hands was available. After each trial, they were provided with terminal visual feedback from the computer screen. On the screen was a summary of the real-time displacement-displacement plot of the right limb against the left limb (a Lissajous figure). One complete movement produced one continuous plot of the Lissajous figure. Thus, the 10-s trials resulted in 10 plots, which overlapped to the degree that the cycles were performed consistently. If a coordination pattern was performed accurately, the Lissajous plots of the 45 Degrees and 135 Degrees patterns were ellipses that were tilted to the right and left, respectively. An accurate 90 Degrees pattern produced a circle. After every fifth trial, an augmented real-time visual feedback replay of the just-completed trial was also provided. The length of one trial was 10 s.

Acquisition trials were performed on 2 consecutive days. The blocked group performed 15 consecutive trials of one pattern before performing the next pattern, so that 45 trials in total were performed on each day. Three participants practiced each pattern in either the first, second, or third ordinal position on each day of practice (counterbalancing for potential order and carry-over effects). The random group performed the patterns in a predetermined random order, with the constraints that each pattern had to be performed 15 times and that no more than two trials on any one pattern would be performed consecutively.

All participants underwent two retention tests. The retention tests comprised six trials, two trials of each pattern, administered in a random order that was the same for all participants. Retention Test 1 was performed before the acquisition phase on the 2nd day. Retention Test 2 was performed 1 week after the 2nd day in the acquisition phase.

Analyses

Point estimates of relative phase were determined after the position and speed in the limbs had been rescaled to the interval (-1, 1) for each cycle. We calculated the phase angles by using the method described by Scholz and

Kelso (1989, p. 129). The difference in the phase angles between the limbs was determined at the positions of peak extension and peak flexion for each cycle. The primary measure of performance was the root mean square error (RMSE) relative to each coordination goal (45 Degrees, 90 Degrees, and 135 Degrees relative phase). The RMSE provides a composite measure of performance accuracy and consistency.(n1)

The 45 trials performed in a day were divided into three blocks of 15 trials each. A 2 (group: blocked, random) x 2 (day) x 3 (block) analysis of variance (ANOVA), with repeated measures on the last two factors, was conducted on the acquisition phase data. A 2 (group) x 2 (retention day: before the 2nd day of practice, after 1 week of no practice) x 3 (pattern) ANOVA was performed on the retention test data. We used the Tukey HSD method for post hoc comparisons of means. The level adopted for statistical significance was $p < .05$ for all tests.

Results

The RMSE in Experiment 1 is illustrated in Figure 1. The only significant finding in acquisition was that both groups improved from Day 1 to Day 2, $F(1, 16) = 31.26$, $p < .001$. The retention test at the beginning of Day 2 of practice was performed with more error than the second retention test, $F(1, 16) = 13.18$, $p < .01$. Although Figure 1 shows that the random group performed better on the second retention test than the blocked group, the Group x Day interaction was not significant, $F(1, 16) = 1.74$, $p = .20$. The effect size was 0.03 for the random-blocked difference in the first retention test and 0.54 in the delayed test.

Discussion

The findings failed to demonstrate a contextual interference effect in the learning of three new bimanual coordination patterns.

However, the absence of a contextual interference effect may be interpreted in different ways. As suggested by Newell and McDonald (1992), researchers have characterized the contextual interference effect in the literature on the basis of studies in which tasks that involve a rescaling of a previously learned movement pattern have been used, and have indexed that effect on the basis of variables that describe movement outcome. Thus, contextual interference effects may be limited to only those specific demonstrations of learning and may not be applicable for learning tasks that require a new coordination pattern. Such a conclusion could severely undermine the potential application of previous contextual interference studies to practical situations.

On the other hand, in the second retention test the RMSE data showed small but nonsignificant retention differences in favor of the random group. The absence of statistically significant differences in retention could have resulted from the way in which the practice sessions were arranged. In this experiment, participants underwent a blocked practice order for each of the coordination patterns on both days of practice. That arrangement is not the typical manner in which blocked practice is conducted in studies of contextual interference. Rather, blocked practice is often provided in a rather strict way whereby all practice trials on one pattern are completed at once; that is, the task is not practiced again in the acquisition period. It is possible that practicing each of the tasks on the 1st day in a blocked order, then practicing the tasks (in a blocked order) again on the 2nd day, gave the participants more opportunity to practice in a manner that moderated the effect normally seen when comparing random and blocked practice conditions.

Thus, to obtain more convincing evidence that the findings in the present experiment exclude contextual interference effects when learning new patterns of coordination, one should also see an absence of random--blocked differences when the blocked practice conditions are similar to those used in previous contextual interference studies (i.e., when completely blocked practice schedules are used). Our goal in Experiment 2 was to compare the effects of random practice with the more typical experimental treatment of blocked practice.

EXPERIMENT 2

Method

Participants

Twelve students in the kinesiology department at McMaster University participated. None of the students had been involved in Experiment 1. They were right-handed and between 18 and 24 years of age, and they were randomly assigned to either the blocked or random group.

Procedure

The acquisition phase lasted 3 consecutive days. The blocked group performed 45 trials of one pattern on the 1st day, practiced a second pattern on the 2nd day, and the remaining pattern on the last day. We completely counterbalanced the order of practice of the three coordination patterns across the 6 students in the blocked group (by using a Williams square design). The random group was treated similarly to the random group in Experiment 1. Only one retention test was performed, which involved administering in a predetermined random order 5 trials of each pattern 1 week after the last day in the acquisition phase. All other procedures were the same as in Experiment 1.

Analyses

The 45 trials in a day were divided into three blocks of 15 trials each. The acquisition phase was thus composed of three blocks per day for 3 days. The blocked group performed three blocks of the same pattern in a day; the random group performed blocks of trials that comprised all three patterns. A 2 (group: blocked, random) x 3 (day) x 3 (block) ANOVA, with repeated measures on the last two factors was performed on the acquisition phase data. A 2 (group) x 3 (pattern) ANOVA was conducted on retention test data. All other statistical procedures were similar to the previous study.

Results

The results for RMSE are shown in Figure 2. Each day revealed clear differences between the blocked and random groups on Trial Blocks 2 and 3 but not on Block 1 (which involved initial practice with a new pattern on each day for the blocked group). Those observations were substantiated by a Group x Block interaction, $F(2, 20) = 15.76$, $p < .001$, and post hoc Tukey tests. The only other significant findings were main effects for day, $F(2, 20) = 14.24$, $p < .001$, and block, $F(2, 20) = 6.35$, $p < .01$.

A retention test performed 1 week after the final day of practice revealed a large learning advantage following random practice. The differences between random and blocked practice in retention for RMSE are illustrated in Figure 2; the group main effect difference was significant, $F(1, 10) = 11.79$, $p < .01$. One interesting finding that was hidden in the group means was that every participant in the random group had a lower RMSE on the retention test than the best participant in the blocked group. The effect size for the random-blocked difference in retention was 0.70.

Discussion

Our purpose in the present experiment was to test for contextual interference effects by using a research paradigm that more closely parallels previous contextual interference studies. To do that, we asked participants in blocked conditions to practice a new bimanual coordination pattern on each of 3 separate days of practice. Contextual interference effects similar to those found in earlier studies were produced in the present study. Following the first block of practice on each day, the blocked group performed the task more accurately than the random group. One difference between that finding and the results of previousB>interference research is that in the earlier research, the advantage in practice for blocked practice usually occurred very quickly, often within several trials of initial practice on a task (e.g., Lee & Magill, 1983; Shea & Morgan, 1979; Shea & Zimny, 1983). In the present study, however, at least 15 trials of practice were needed before students in the blocked group demonstrated a performance advantage over students in the random practice group.

The other key finding in this study was the advantage in retention following random practice. Although there was a similar trend in the delayed retention test in Experiment 1, the retention advantage was clear and quite pronounced in this study. Together, the acquisition and retention findings in this study refute the suggestion that contextual interference effects occur only for tasks in which subjects learn a new scaling of a previously acquired movement pattern (Newell & McDonald, 1992).

GENERAL DISCUSSION

The most important result of the present studies was the finding that contextual interference effects arise in motor tasks that require the acquisition of a new pattern of coordination. That conclusion is suggested by several observations. First, we know from previous research that when subjects attempt to perform a 90 Degrees coordination pattern (Lee et al., 1995; Zanone & Kelso, 1992) or a 45 Degrees or a 135

Degrees pattern (Fontaine et al., 1997), the movement is attracted toward either an in-phase or an antiphase coordination pattern. Thus, those patterns are not in the subjects' repertoire prior to practice. The patterns can be acquired with practice, however, and improvements in pattern quality can be indexed by relative phase. Thus, the observed differences caused by random versus blocked practice can logically be assumed to reflect true differences in learning a new motor coordination pattern.

The present findings (Experiment 2, in particular) were like the typical findings in contextual interference research. Acquisition performance was facilitated by blocked practice, but random practice resulted in better retention. One interesting finding, however, was that the acquisition effect that normally occurs during very early practice trials in many experiments was absent in this study. Not until the second block of acquisition trials on each day did blocked practice facilitate performance.

That finding may lend some support to Newell and McDonald's (1992) hypothesis that the influence of random practice occurs following the first stage of skill acquisition. One possibility is that practice schedule effects do not influence the processing operations that are involved in figuring out what to do (Ackerman, 1988; Anderson, 1982; Fitts, 1964) but, rather, are manifested more strongly during the second and third stages of acquisition. That hypothesis would explain the retention findings in Experiment 1. Both random and blocked groups performed similarly in retention following the 1st day of practice. However, the retention advantage favoring the random group was much larger and approached statistical significance 1 week after the 2nd day of practice.

The finding that contextual interference effects for the present task became stronger as the amount of practice increased has potential importance for theory. Explanations of contextual interference effects (Lee & Magill, 1983, 1985; Shea & Morgan, 1979; Shea &

Zimny, 1983) have been based on cognitive representations, traditionally thought to be involved most prominently in the first stage of skill acquisition (e.g., Fitts, 1964). Our current research efforts are being directed toward the possibility that the effects of random practice may interact with the skill level of the learner and the nature of the task.

Together, the results of the present experiments suggest that contextual interference effects not only are evident in tasks that require the acquisition of a new movement coordination pattern but may also be interdependent with the individual's stage of learning. Beyond the theoretical importance of that suggestion is the reassurance it provides to instructors and rehabilitation specialists who advocate random schedules of repetitions in practice and treatment (Schmidt & Bjork, 1992; Winstein, 1991).

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NOTE

(n1.) The RMSE was also decomposed into measures of accuracy and consistency. We analyzed the absolute values of the mean difference between the performed relative phase and the goal relative phase (ACE) and the standard deviations of the performed relative phase (SD) to examine whether RMSE differences were caused by either or both accuracy and consistency in producing the goal bimanual patterns. In all cases in both Experiments 1 and 2, the significant group differences in RMSE were mirrored by significant differences in movement accuracy (ACE), but not consistency (SD).

FIGURE 1. The root mean square error relative to each coordination goal (45 Degrees,' 90 Degrees, and 135 Degrees relative phase) found for participants in the blocked and random groups in Experiment 1. Performance means on three blocks each of 2 practice days and in retention tests before the 2nd day's acquisition phase and 1 week after the 2nd day in the acquisition phase have been plotted.

FIGURE 2. The root mean square error relative to each coordination goal (45 Degrees, 90 Degrees, and 135 Degrees relative phase) for participants in the blocked and random groups in Experiment 2. Performance means on three blocks each of 3 practice days and in a retention test 1 week after the 3rd day in the acquisition phase have been plotted.

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