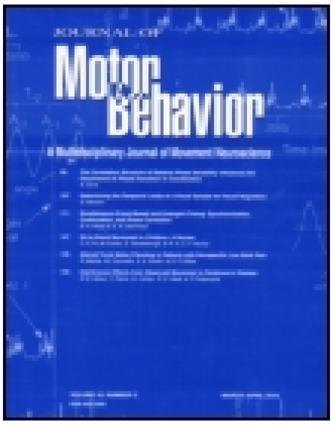

Journal of Motor Behavior
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/vjmb20

Differential Transfer Benefits of Increased Practice for Constant, Blocked, and Serial Practice Schedules

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Published online: 01 Apr 2010.

Journal of Motor Behavior, 2002, Vol. 34, No. 4, 353–365

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ABSTRACT. The effects of practice schedule and amount of practice on the development of the generalized motor program (GMP) and on parameter estimation were investigated. Participants (N = 108) practiced the same relative timing but different absolute durations of a multisegment timing task. Practice schedules (constant, blocked, or serial) were crossed with amounts of practice (low and high). Inclusion of a constant practice condition allowed the authors to investigate the variability of practice prediction. Participants practiced the same proportional durations in a serial or a blocked schedule, which enabled the authors to examine contextual interference. A constant practice schedule enhanced GMP performance when task parameters remained the same, but varied practice schedules were beneficial when task parameters changed. A serial as opposed to a blocked practice schedule was superior when the performance of a task governed by a different GMP was required. Increased practice led to a consolidated task representation that was unavailable for updating.

Key words: amount of practice, contextual interference, generalized motor program, movement parameters, variable practice

Investigation of the variability of practice prediction derived from Schmidt's (1975) schema theory has provided the impetus for much of the research concerned with the influence of practice schedule on the learning of motor tasks (Magill & Hall, 1990; Schmidt & Bjork, 1992; van Rossum, 1990). According to schema theory, movements comprised of segments that have the same proportional duration or relative timing structure belong to the same movement class. One can scale those movements by assigning before the movement an absolute duration to each movement segment as well as to the entire movement. The relative timing structure becomes invariant with practice and is referred to as the *generalized motor program* (GMP). The program parameters, which are the varying features of the GMP, are selected on the basis of the schemata or rule developed from past experiences with the program.

Learning to parameterize effectively is necessary for movement acquisition (Schmidt, 1975). Furthermore, a prediction of the schema theory is that parameterization capability is a product of the number of times that the outcome of the action, signaled by knowledge of results (KR), and its parameters are paired during practice. That is, increased use of different parameters across movements governed by the same GMP increases the strength of the schema. Accordingly, increased variability in assigning parameters during practice of movements governed by the same GMP should enhance retention of the movements as well as transfer to novel movements within the same movement class. Most important, the variability of practice hypothesis accounts for movements that belong exclusively to a single movement class (i.e., that are governed by the same GMP). However, the variability of practice prediction does not account for the improved performance observed when the movements belong to different movement classes (i.e., are governed by different GMPs). Furthermore, in a critical review of the empirical support for the variability of practice prediction, van Rossum (1990) concluded that although the evidence for the effect is weak, investigations of variability remain important to motor learning. He specified, however, that the following question needs to be asked in future research: Under what conditions and to what degree is variability of practice more instrumental than constant practice to motor learning? Moreover, van Rossum recommended that in future research on that phenomenon, investigators should systematically delineate the effects of variation in practice schedules on motor learning while avoiding the significant shortcomings of the previous variability of practice research.

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In more recent investigations of factors supporting motor learning, Schmidt's (1975) variability of practice hypothesis has often been compared with a similarly high-impact motor learning phenomenon, called *contextual interference*. Contextual interference refers to the situation in which there is interference among multiple tasks being learned across practice trials. Practice under a condition of high contextual interference (e.g., when multiple tasks are practiced in a random order) typically results in less proficient performance than practice under a condition of low contextual interference (e.g., when multiple tasks are practiced in a blocked order). Those findings are reversed for retention and transfer tests, however; in those tests, performance is more proficient for the high contextual interference practice condition than for the low contextual interference practice condition. In both variability of practice and contextual interference predictions, the impact of introducing variation into the performance context is taken into account. However, the variability of practice prediction incorporates change introduced by task and person variables, whereas the contextual interference prediction incorporates the effects of changes in the organization of the practice context on motor learning. Since being introduced into the motor learning literature by J. B. Shea and Morgan (1979), evidence for the contextual interference effect has garnered considerable support from both laboratory and field-based investigations (Brady, 1998). Furthermore, several theoretical explanations have been advanced concerning the advantages of random practice or, conversely, the limitations of blocked practice in motor learning.

After conducting an extensive review documenting beneficial high contextual interference practice effects, Magill and Hall (1990) hypothesized that such effects are obtained in multisegment movements only when practiced tasks are governed by different GMPs and not when they are governed by the same GMP. That conclusion is consistent with the reconstruction hypothesis proposed by Lee and Magill (1983, 1985) that performing intervening tasks in a random practice schedule causes the learner to forget the action plan for the task he is required to learn. The action plan for a given task must therefore be constructed before each succeeding performance of the task. Action plan reconstruction is not needed for performance of a task in a blocked practice schedule condition because there are no intervening tasks before that task is next performed.

According to Magill and Hall (1990), action plan reconstruction for tasks governed by different GMPs requires both the reconstruction of the GMP and the assignment of appropriate parameters. Action plan reconstruction for tasks governed by the same GMP does not require reconstruction of the GMP, however, but only the assignment of appropriate parameters. The reconstruction process determines the amount of effortful processing during practice. The effortful processing, in turn, determines the strength of the task representation. Thus, the performance situation presented by random practice of tasks governed by the same GMP is not difficult enough to cause contextual interference effects. Reassignment of parameters alone does not lead to the effortful processing necessary for enhanced learning. In contrast, practice of tasks governed by different GMPs in a random practice schedule requires the reconstruction of the entire action plan (i.e., both parameters and GMPs). The reconstruction of the entire action plan makes it necessary for the learner to do the effortful processing that enhances learning.

Magill and Hall's (1990) hypothesis has received mixed support in the literature (Brady, 1998; Hall & Magill, 1995; Lee, Wulf, & Schmidt, 1992; Sekiya, Magill, & Anderson, 1996; Sekiya, Magill, Sidaway, & Anderson, 1994; Wulf, 1992; Wulf & Lee, 1993) and has been subjected to several revisions. In contradiction of Magill and Hall, Wulf and Lee concluded that random practice is more effective than blocked practice for learning the GMP but is less effective for learning parameter estimation for tasks governed by the same GMP. Sekiya et al. (1994) proposed that for retention tests, a contextual interference effect would be found for parameter estimation but not for the generalized motor program, regardless of whether the practiced tasks are governed by the same or by different GMPs. No support was provided in a subsequent test of that prediction (Sekiya et al., 1996), however. Finally, Hall and Magill (1995) conducted two complex experiments in which blocked and random practice schedules were combined with multiple tasks that were governed by either the same or different GMPs, and they included an extensive number of retention and transfer tests. The findings of those experiments provided some support for Magill and Hall's earlier conclusion. They went on to assert that the amount of practice variability influences the learning of tasks when the tasks are governed by the same GMP, whereas contextual interference influences the learning of tasks when the tasks are governed by different GMPs.

Magill and Hall's (1990) hypothesis has received further support in Brady's (1998) review of the contextual interference effect in both applied and laboratory-based research. Brady proposed that one can minimize the apparent differences in findings between the laboratory- and field-based contextual interference research (i.e., the contextual interference effect is more prevalent for variations between motor programs for laboratory tasks and more robust for variations within motor programs for more complex applied tasks). By examining closely the research and factors militating against the effect in the field-applied research, Brady concluded that specific factors (index of task difficulty, amount of practice, and participants' interest in the task), all present in the field-based research, act to reduce the difference between the blocked and random practice groups. Therefore, those factors interact with the schedule effects, leading to different outcomes in field-based investigations of contextual interference. Furthermore, he indicated that when one takes into account the person's interest in the tasks, the amount of practice of the task, and task difficulty, the apparent inconsistency between the laboratory- and field-based findings disappears. Therefore, both the field-based and the laboratory-based research supported Magill and Hall's contention that the amount of practice variability influences same motor program learning whereas contextual interference influences the learning of different motor programs.

However, in direct contrast to Magill and Hall's (1990) hypothesis about same generalized motor programs, Lai and Shea (1998) recently found a beneficial effect for a constant over a serial practice schedule when the same GMP governed the tasks. They found a beneficial effect for a serial over a constant practice schedule for parameter estimation, however. Those findings led Lai and Shea (1998, 1999) to propose that GMP learning is enhanced by acquisition factors that increase response stability and not by variation in the practice context. According to Lai and Shea, factors that increase response stability would enhance the focus on maintaining the same practice conditions across acquisition trials and on minimizing changes in the practice context. However, acquisition factors that support parameter estimation would enhance the focus on changes in the practice context.

Our purpose in the present experiment was to investigate the effects of practice on GMP learning and parameter estimation across varying conditions and amounts of practice. We investigated contextual interference effects by having three multiple-segment timing tasks that were governed by the same GMP practiced in either a serial or a blocked schedule. In addition to having serial and blocked practice schedule conditions, we included in the present experiment a constant practice condition in which the learner practiced only a single task that had the same program as different tasks practiced by the other practice groups. For the constant practice group, however, the program and the parameters were the same throughout practice. The inclusion of the constant practice condition allowed us to investigate Schmidt's (1975) variability of practice prediction. That topic has received less attention for several years because researchers have shifted their focus to explaining the benefits of contextual interference introduced by variation in the organization of the different practice schedules practiced rather than investigating variability introduced by changes in the movement pattern. Finally, the effect of amount of practice on contextual interference and variability of practice findings was investigated. The amount of practice provided during acquisition has frequently been cited as a possible determinant of experimental outcomes in studies concerned with contextual interference effects (Proteau, Blandin, Alain, & Dorion, 1994; Sekiya et al., 1996; Sekiya et al., 1994; C. H. Shea, Kohl, & Indermill, 1990). The impact of different amounts of practice and variable practice conditions on motor learning has received few direct tests, however, particularly with respect to GMP learning and parameter estimation. Although Sekiya et al. (1996) found that amount of practice had no influence on contextual interference effects, amount of practice has been confounded with practice schedule in all recent studies on variable and constant practice effects (Lai & Shea, 1998; Lai, Shea, Wulf, & Wright, 2000; Wulf & Schmidt, 1997).

The use of three posttests and a transfer paradigm in which systematic changes were made in task characteristics across three tests provided the basis for an examination of the previously presented predictions for variability of practice and contextual interference. Posttest 1 consisted of the performance of Acquisition Task A: same GMP and same parameters. The only change between acquisition and Posttest 1 was that KR was provided during acquisition and was withdrawn during Posttest 1. The withdrawal of KR allowed us to directly test immediate performance enhancement while minimizing forgetting effects. In that condition, there was no change in either the GMP controlling the task or its parameters. Posttest 2—same GMP transfer test—consisted of a novel task that was controlled by the same GMP practiced but had different parameters than the acquisition tasks. Posttest 3—different GMP transfer test—consisted of a novel task that was controlled by a different GMP and had different parameters than the acquisition tasks.

According to the variability of practice prediction (Schmidt, 1975), performance should be superior for both the blocked and serial practice schedule conditions than for the constant practice condition. The superiority of those conditions is the effect of learners' experiencing more practice variability in acquisition for the blocked and serial practice conditions than for the constant practice condition. According to Magill and Hall's (1990) prediction, because the same GMP governs the tasks practiced during acquisition, performance on all three posttests should be similar for the blocked and the serial practice schedule conditions. Wulf and Lee (1993) would predict superior GMP learning for participants in the serial than for those in the blocked practice schedule condition but superior parameter estimation for participants in the blocked practice than for those in the serial practice schedule condition on Posttests 1 and 2, in which learners use a motor program previously practiced. Sekiya et al. (1994) predicted that parameter estimation but not GMP learning would be superior for the serial than for the blocked practice schedule condition for the first posttest—same motor program and parameters condition. Lai and Shea (1998, 1999; Lai et al., 2000) would predict superior same motor program learning but not parameter estimation for the constant practice schedule group than for the serial practice schedule group for Posttests 1 and 2. Conversely, those investigators would predict that parameter estimation within the same motor program would be better for the serial practice schedule group than for the constant practice schedule group on Posttests 1 and 2.

Method

Participants

Participants were 108 right-handed undergraduate students, who received class credit for participation. All participants were naive to our purpose in the experiment and had no previous experience with the experimental apparatus.

Apparatus

The apparatus was similar to the one used by Wulf and colleagues (Wulf & Lee, 1993; Wulf & Schmidt, 1988, 1989); it consisted of a wooden board (64 × 42 cm) on which were placed four 3-cm-diameter buttons that were 18.5 cm apart from one another and arranged in a diamond pattern. The buttons were modified keys from a computer keyboard that were adapted for tapping and integrated with an IBM PS/2 computer so that movement timing could be measured. We developed a computer program to control the experimental sequence and data collection.

Tasks

In the tasks used in the experiment, the participants had to press the buttons in a prescribed sequence, beginning with the button closest to them and progressing in a clockwise direction around the diamond pattern to the button located on the right side of the apparatus. Thus, each task consisted of three movement segments: Segment 1 was from Button 1 to Button 2, Segment 2 was from Button 2 to Button 3, and Segment 3 was from Button 3 to Button 4. The movement segments for each task were to be produced in the times specified on the computer screen as the goal movement times (MTs). The goal MTs for Task A were 200–400–300 ms, the goal MTs for Task B were 250–500–375 ms, and the goal MTs for Task C were 300–600–450 ms. The segment MTs for each task were of equal proportion relative to their total MTs. Thus, the participants had to use same relative timing (.22–.44–.33) to perform each acquisition task. Task A was used for Posttest 1. The segment goal MTs for Task D (350–700–525 ms) were different from those used for the acquisition tasks, but their relative timing was the same as for the acquisition tasks (.22–.44–.33). The segment goal MTs for Task E (700–525–350 ms) not only were different from those used for the acquisition tasks, but their relative timing (.44–.33–.22) also differed from that of the acquisition tasks. Tasks D and E were used for Posttests 2 and 3, same GMP–different parameters transfer test and different GMP transfer test, respectively.

Design

Three acquisition practice schedule conditions (constant, blocked, and serial) were crossed with two amounts of practice conditions (high and low), which resulted in six independent groups of equal size (n = 18). Those were the constant schedule–high practice, the blocked schedule–high practice, the serial schedule–high practice, the constant schedule–low practice, the blocked schedule–low practice, and the serial schedule–low practice groups. A total of 54 and 162 practice trials were performed during acquisition by the low and the high amounts of practice conditions, respectively. Practice trials were administered in blocks of 6 trials so that the low amount of practice group performed 9 blocks of 6 trials and the high amount of practice group performed 27 blocks of 6 trials. Only Task A was performed in the constant schedule condition, whereas Tasks A, B, and C were performed in the blocked and the serial schedule conditions.

Tasks were practiced in one of three orders (A, B, and C; B, C, and A; or C, A, and B). For both blocked and serial conditions, task order was counterbalanced across participants. In the blocked schedule condition, all trials on one task were completed before the next task was introduced. Thus, for the low practice condition, three consecutive blocks of 6 trials (18 trials) were administered; and for the high practice condition, nine consecutive blocks of 6 trials (54 trials) were administered for each task, according to the designated task order (e.g., A, B, and C). In the serial schedule condition, the designated serial order (e.g., A, B, and C) was repeated across blocks of practice trials 18 times for the low practice condition or 54 times for the high practice condition. Those procedures provided an equivalent amount of practice for Task A for the constant schedule–high practice, the blocked schedule–high practice, and the serial schedule–high practice groups.

Following acquisition practice, all participants were administered three consecutive posttests. Participants were administered Posttest 1, same GMP–same parameters, and Posttest 2, same GMP–different parameters transfer tests, before Posttest 3, the transfer test for a different motor program. We designed the posttests' order to control the amount of variation introduced by each subsequent test and to allow testing of the effects of practice on same motor programming performance before introducing practice of a different motor program to the participant. Each test consisted of 12 trials. Task A was performed for Posttest 1, same GMP–same parameters test; Task D was performed for Posttest 2, same GMP–different parameters transfer test; and Task E was performed for Posttest 3, the different GMP–different parameters transfer test.

Procedure

Participants were tested individually in a room free of distraction. While they were seated in front of the apparatus, participants were instructed that they would be performing a timing task and that the task should be performed as accurately as possible. The order in which the buttons were to be tapped was demonstrated. We emphasized that the time intervals between button taps should be the same as the times specified on the computer screen. Instructions were given before the administration of acquisition and before each posttest.

The letter denoting the task version and the goal MTs were presented on the computer screen for 4 s before each trial. The task letter and the goal MTs were removed from the computer screen, which remained blank for a period of 4 s. The participant performed the task within that 4-s interval. If the participant did not complete the movement or made an error in pressing the buttons, an error message was presented and the trial was repeated. We presented KR following each trial during acquisition by displaying the goal MTs above the participant's actual MTs on the computer screen. The goal and actual MTs were displayed in different colors so that they could be easily distinguished. KR was displayed for 7 s. That display was followed by a 3-s interval during which the participant was signaled to prepare for the next trial. The intertrial interval for all acquisition trials was 10 s.

The three posttests were administered following acquisition. With the exception that KR was not provided, the procedures used for the posttest trials were the same as those used for acquisition. Posttest 1 was administered 5 min following the last acquisition practice trial and consisted of 12 trials of Task A. The goal MTs for Task A were displayed for 4 s; the participants then had 4 s to complete their response. During a 10-s interval following the response, the participants were signaled to get ready for the next trial. Posttest 2, the same GMP transfer test, was administered 1 min after the completion of Posttest 1 and consisted of 12 trials of Task D. Posttest 3, the different GMP transfer test, was administered 1 min after the completion of Posttest 2, the same GMP transfer test, and consisted of 12 trials of Task E. All procedures followed for the transfer tests were the same as those described for Posttest 1.

Measurement

Movement time (MT) for each segment was recorded following each trial in acquisition and in each posttest. MT was the time from contact with the start button to contact with the next button in the movement sequence. We computed absolute error proportion, *AE*(prop), a measure of the accuracy of the GMP, by summing the absolute differences between the goal proportions and the actual proportions for each segment. The *AE*(prop) measure is independent of errors in time parameterization (Wulf & Lee, 1993). We used absolute constant error (*ACE*) as a measure of absolute timing performance or parameter estimation. We computed *ACE* by taking the absolute difference between the overall goal MT and the actual overall MT.

Results

AE(prop) and *ACE* measures were averaged into blocks of six trials for the analyses. The findings for the analyses conducted on the last two blocks of acquisition trials are presented. Those analyses allowed us to directly compare acquisition performance for the practice schedule conditions. A direct comparison across all acquisition trial blocks in the present experiment was not possible because of the unequal number of acquisition trials administered in the low and the high practice conditions. Therefore, we used separate 3 × 2 × 2 (Practice Schedule × Amount of Practice × Trial Block) analyses of variance (ANOVAs) with repeated measures on the last factor to analyze *AE*(prop) and *ACE* measures for acquisition and for Posttests 1, 2, and 3. The rejection region was $p < .05$ for all statistical tests. In post hoc testing, we identified the locus of any significant effects. *AE*(prop), that is, relative timing errors, for all experimental conditions are displayed in Figure 1.

Acquisition

AE(prop)

In Figure 2, *AE*(prop) measures are displayed for each organization of Practice Schedule × Amount of Practice across all trial blocks. There was a significant Practice Schedule × Amount of Practice × Last Blocks of Trials interaction, $F(2, 102) = 4.63, p < .05$.

An additional analysis of the acquisition data is shown in Figure 3, which displays *AE*(prop) measures for the last two acquisition trial blocks for all low and high practice schedule groups. *AE*(prop) was greatest for the serial condition ($M = .15$, $SD = .05$), and there was little difference between the blocked ($M = .12$, $SD = .05$) and the constant ($M = .12$, $SD = .04$) conditions across trial blocks. For the high practice condition, those findings were consistent across trial blocks; *AE*(prop) was greater for the high practice–serial group than for the high practice–blocked and –constant groups for both last trials blocks. *AE*(prop) findings were not as consistent across last trials blocks for the low practice condition, however. *AE*(prop) decreased across last trials blocks for the low practice–blocked group. Although *AE*(prop) was greater for the low practice–blocked group than for the low practice–constant and low practice–serial groups for Last Blocks of Trials 1, it was lower for the low practice–blocked group than for the low practice–constant and low practice–serial groups for Last Blocks of Trials 2. It is interesting that although increased practice resulted in less *AE*(prop) for the constant and blocked practice schedule conditions, it had a smaller effect on *AE*(prop) for the serial practice schedule condition. The greater stability in *AE*(prop) measures across trial blocks for the high than for the low practice condition is consistent with the finding that *AE*(prop) was less for the high practice condition ($M = .11$, $SD = .04$) than for the low practice condition ($M = .15$, $SD = .05$). Those findings accounted for the three-way interaction as well as the effects of practice schedule, $F(2, 102) = 4.43, p < .05$, and amount of practice, $F(1, 102) = 15.71, p < .001$. All other findings were not significant.

ACE

There was a significant Practice Schedule × Amount of Practice × Last Blocks of Trials interaction, $F(2, 102) = 4.92, p < .05$. In Figure 4, *ACE* measures are displayed for each organization of Practice Schedule × Amount of Practice across all trial blocks.

There was a significant practice schedule effect, $F(2, 102) = 7.02, p < .01$. In Table 1 are presented *ACE* mea-

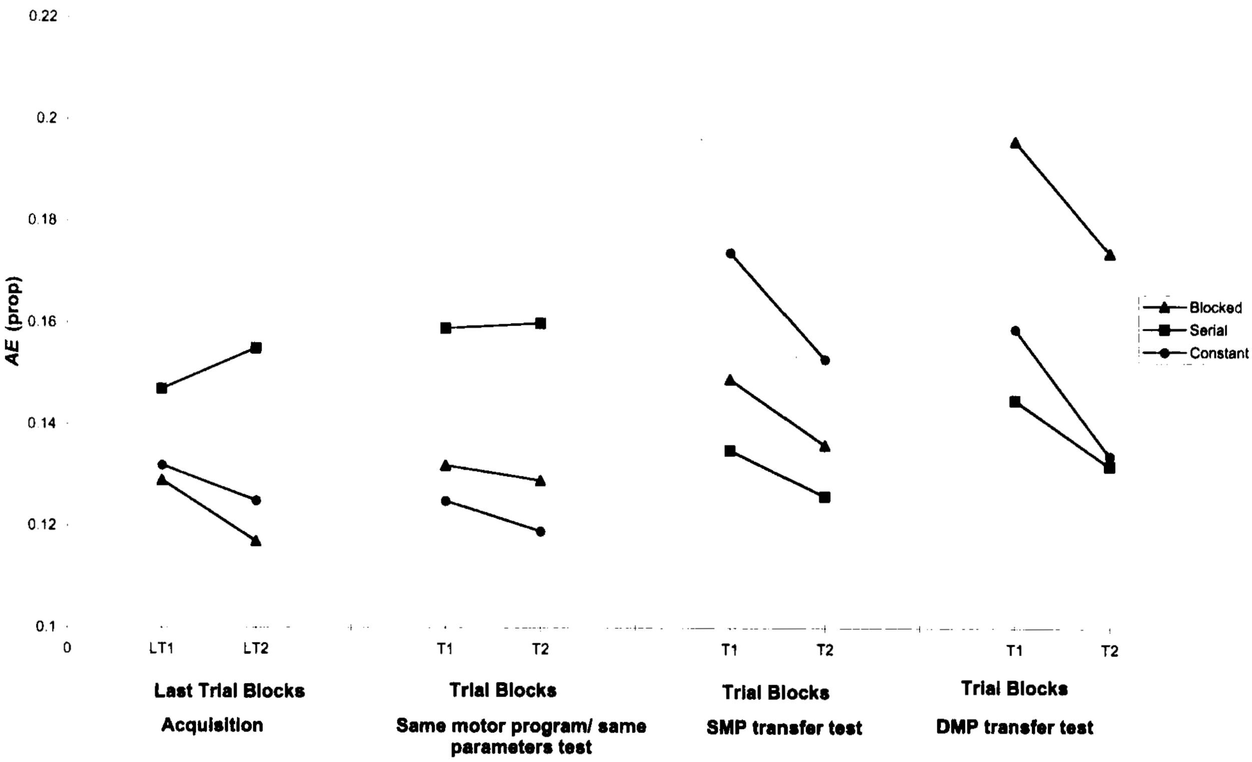

FIGURE 1. Errors in relative timing, *AE*(prop), for the constant, blocked, and serial practice groups across all practice and posttest conditions. SMP = same motor programs; DMP = different motor programs.

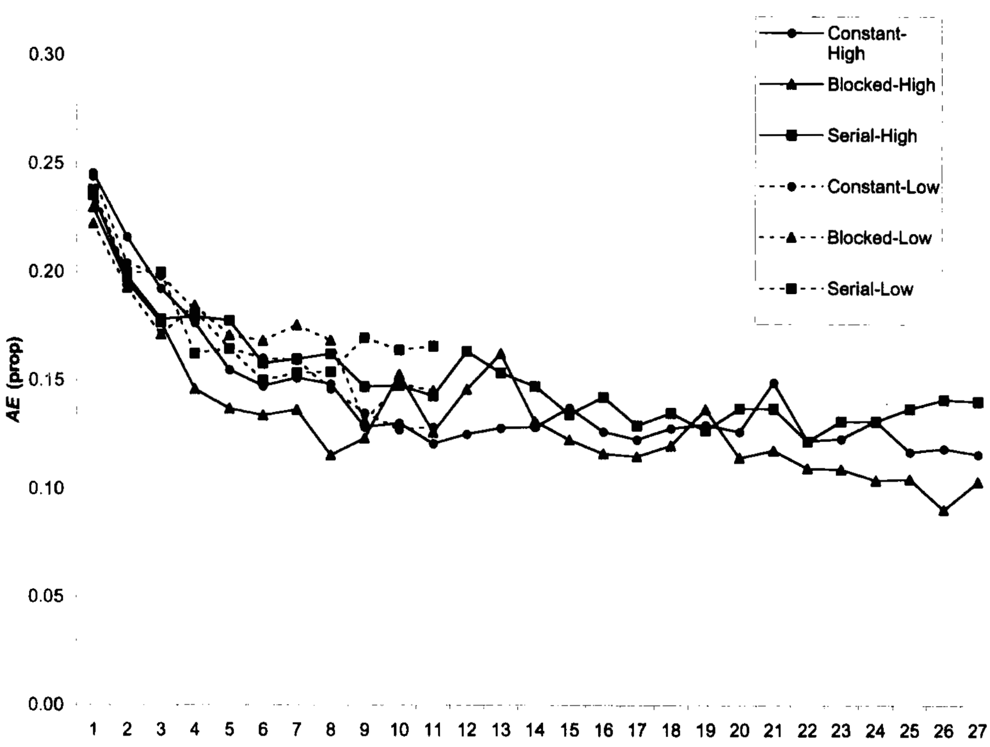

FIGURE 2. Errors in relative timing, *AE*(prop), for the high and the low constant, blocked, and serial practice groups across acquisition trial blocks.

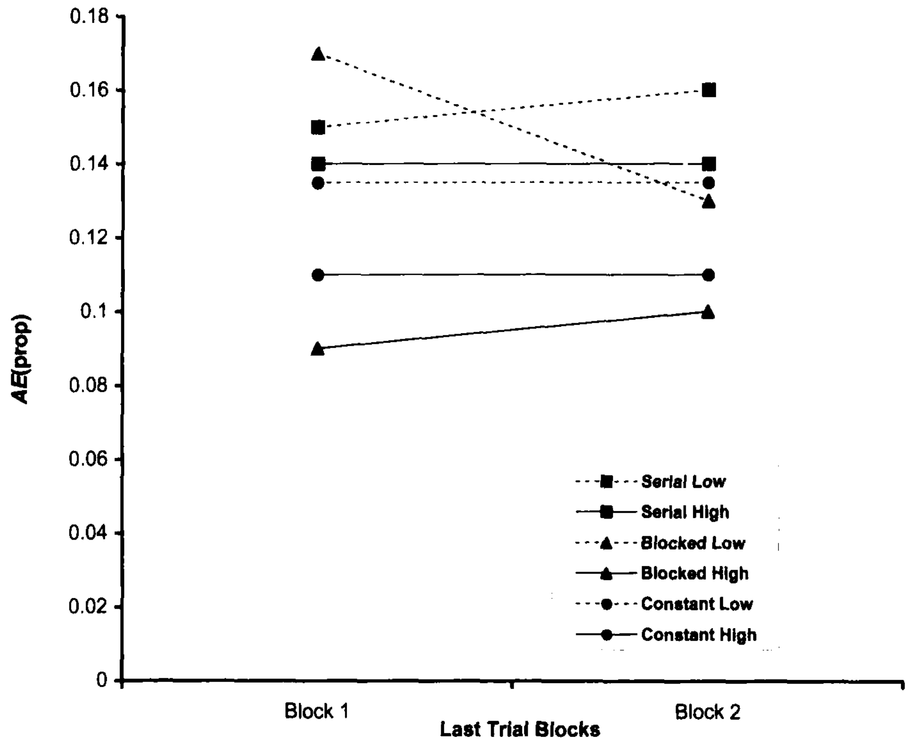

FIGURE 3. Errors in relative timing, *AE*(prop), for the constant, blocked, and serial practice groups for the last two acquisition trial blocks.

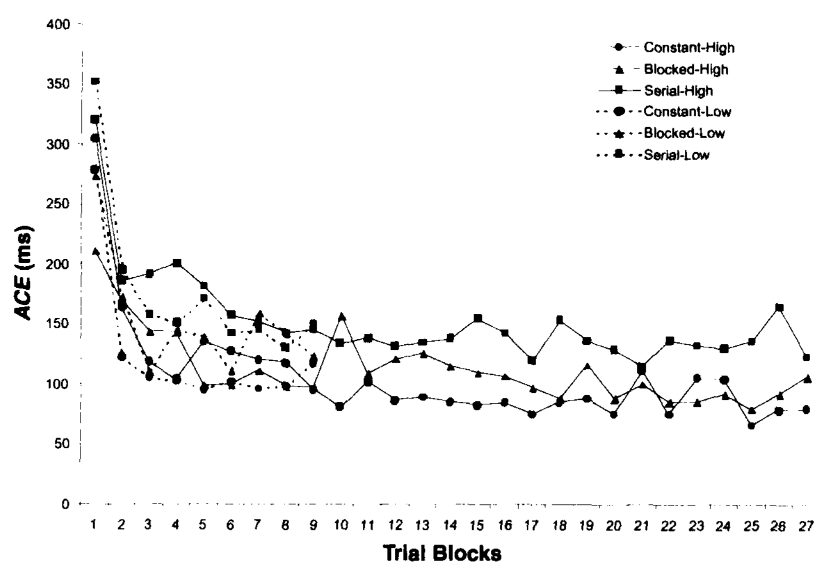

FIGURE 4. Errors in absolute timing, *ACE*, for the high and the low constant, blocked, and serial practice groups across acquisition trial blocks.

sures for the low and the high practice schedule groups. *ACE* was greater for the serial than for the blocked and the constant conditions. That finding accounted for the significant practice schedule effect. Post hoc analysis indicated that the differences between the blocked and the constant conditions and the serial condition were significant. The difference between the blocked and the constant conditions was not significant. *ACE* was lower for the high practice than for the low practice groups in the blocked and the constant practice schedule conditions. *ACE* was approximately the same for the high practice and the low practice groups in the serial practice schedule condition. That find-

TABLE 1
Acquisition *ACE* Mean (*M*) and Standard Deviation (*SD*) Measures for Serial, Blocked, and Constant Practice Schedule Groups

	Low practice		High practice		Overall	
Schedule	*M*	*SD*	*M*	*SD*	*M*	*SD*
Serial	140.41	46.36	144.39	81.90	142.41	66.73
Blocked	133.14	77.33	99.67	45.48	116.41	62.57
Constant	108.51	66.50	79.49	47.44	94.00	56.79
Overall	127.35	63.40	107.85	58.27	117.61	62.00

Note. ACE = absolute constant error.

ing was not uniform across Last Blocks of Trials 1 and 2 for the serial practice schedule condition, however. *ACE* was lower for the low practice–serial group (M = 130.55 ms, SD = 49.66 ms) than for the high practice–serial group (M = 165.27 ms, SD = 105.29 ms) for Last Blocks of Trials 1. The group difference was reversed for Last Blocks of Trials 2, with *ACE* being greater for the low practice–serial group (M = 150.27 ms, SD = 43.07 ms) than for the high practice–serial group (M = 123.51 ms, SD = 58.52 ms). Those findings accounted for the significant Practice Schedule × Amount of Practice × Trial Blocks interaction. The pattern of group differences across trial blocks for *ACE* measures might have reflected the difficulty experienced by participants in the serial practice schedule condition in learning the tasks when parameter values were continuously changing in an unsystematic order across trials. All other findings were not significant.

Posttest 1 (Same GMP–Same Parameters)

AE(prop)

AE(prop) findings for Posttest 1 closely paralleled those for acquisition. The practice schedule main effect was significant, $F(2, 102) = 5.77$, $p < .01$. *AE*(prop) was greater for the serial (M = .16, SD = .06) than for the blocked (M = .13, SD = .05) and the constant (M = .12, SD = .05) practice schedule conditions. Post hoc analysis revealed that the difference between the serial and the blocked practice conditions as well as the difference between the serial and the constant practice conditions were significant. However, the difference between the blocked and the constant practice conditions was not significant. Although *AE*(prop) was less for the high practice (M = .12, SD = .04) than for low practice (M = .14, SD = .05) condition, the effect of amount of practice, $F(1, 102) = 3.68$, $p > .05$, was not significant. All other findings were not significant, $Fs < 1$.

ACE

There was a main effect for trial blocks, $F(1, 102) = 10.01$, $p < .05$. No other significant findings were identified for *ACE* and that test. The effect of practice schedule, $F(2, 102) = 2.33$, $p \leq .05$, was not significant. *ACE* was substantially greater for the blocked (M = 142.80 ms, SD = 106.30 ms) than for the constant (M = 107.00 ms, SD = 73.08 ms) and serial (M = 106.00 ms, SD = 70.50 ms) practice schedule conditions, however.

Posttest 2 (Same GMP–Different Parameters Transfer Test)

AE(prop)

There was a significant Practice Schedule × Amount of Practice × Trial Blocks interaction, $F(2, 102) = 3.58$, $p < .05$; in addition, an effect of trial blocks, $F(1, 102) = 8.75$, $p < .01$, was significant. *AE*(prop) was less for the high practice–blocked group than for the low practice–blocked group, and for the high practice–serial group than for the low practice–serial group, but was greater for the high practice–constant group than for the low practice–constant group. *AE*(prop) decreased between Trials Blocks 1 and 2. That finding was observed for the low practice–constant, the high practice–constant, the low practice–blocked, and the high practice–serial groups. However, there was no appreciable change in *AE*(prop) between Trials Blocks 1 and 2 for the high practice–blocked and the low practice–serial groups. Most important, the practice main means revealed that *AE*(prop) was greater for the constant (M = .16, SD = .06) than for the blocked (M = .14, SD = .05) and the serial (M = .13, SD = .04) practice conditions. That finding accounted for the significant practice schedule effect, $F(2, 102) = 5.86$, $p < .01$. Post hoc analysis revealed that the difference between the constant practice and the blocked practice conditions as well as the difference between the constant practice and the serial practice conditions were significant. The difference between the blocked and the serial practice conditions was not significant. The generality of those findings was limited by amount of practice received during acquisition and transfer test trial blocks. Figure 5 shows *AE*(prop) measures for the low and the high practice schedule groups.

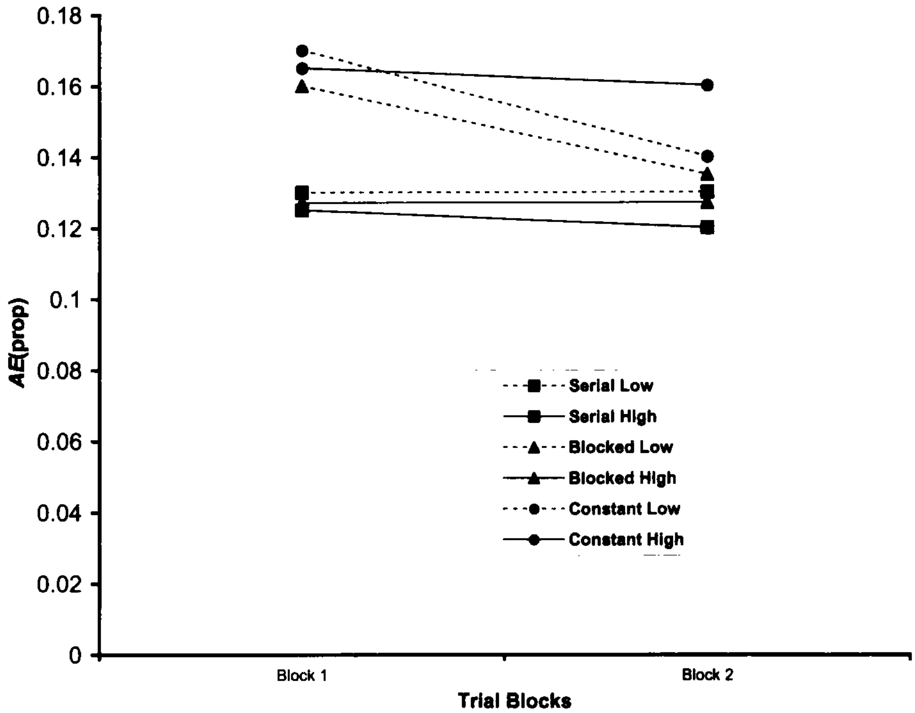

FIGURE 5. Errors in relative timing, *AE*(prop), for constant, blocked, and serial practice groups for Posttest 2, same generalized motor program (GMP)–different parameters transfer test.

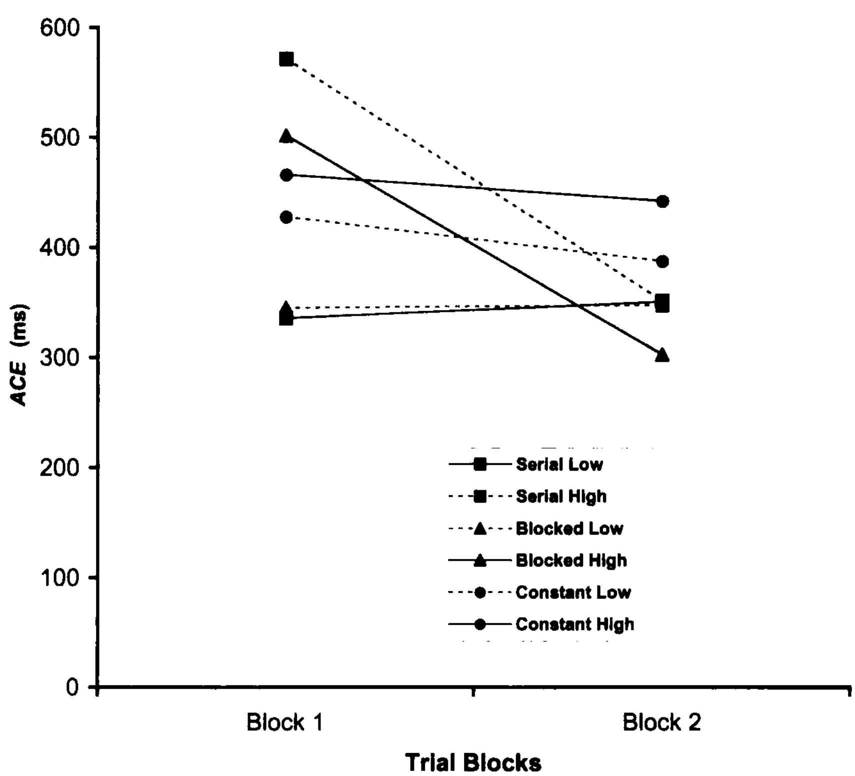

FIGURE 6. Errors in absolute timing, *ACE*, for the constant, blocked, and serial practice groups for Posttest 3, different motor program–different parameters transfer test.

ACE

There was a significant effect of trial blocks, $F(1, 102) = 8.75$, $p < .01$. *ACE* increased between Trial Block 1 (M = 256.90 ms, SD = 149.13 ms) and Trial Block 2 (M = 314.60 ms, SD = 215.10 ms), which accounted for the significant effect of trial blocks. All other findings were not significant, $Fs < 1$.

Posttest 3 (Different GMP–Different Parameters Transfer Test)

AE(prop)

The analysis indicated a significant main effect of practice schedule, $F(2, 102) = 5.14$, $p < .01$. Follow-up tests revealed that *AE*(prop) was noticeably greater for the blocked (M = .18, SD = .08) than for the constant (M = .15, SD = .06) and the serial (M = .14, SD = .05) practice conditions. The difference between the blocked and the constant practice conditions as well as the difference between the blocked and the serial practice conditions were significant. However, the difference between the constant and the serial practice conditions was not significant. A trial blocks main effect was also found, $F(1, 102) = 10.52$, $p < .01$. *AE*(prop) decreased between Trial Block 1 (M = .17, SD = .06) and Trial Block 2 (M = .14, SD = .07), which accounted for the effect of trial blocks.

ACE

There was a significant Practice Schedule × Amount of Practice × Trial Blocks interaction, $F(2, 102) = 5.18$, $p < .01$, a significant Practice Schedule × Trial Blocks interaction, $F(2, 102) = 16.40$, $p < .001$, and the effect of trial blocks, $F(1, 102) = 20.29$, $p < .001$, was significant. In Figure 6, *ACE* measures are shown for the low and the high practice schedule groups across Trial Blocks 1 and 2. *ACE* was greater for the constant (M = 430.53 ms, SD = 285.20 ms) than for the blocked (M = 373.97 ms, SD = 226.00 ms) and the serial (M = 402.12 ms, SD = 266.61 ms) practice schedule conditions. In addition, *ACE* was greater for the high practice (M = 438.89 ms, SD = 262.30 ms) than for the low practice (M = 365.50 ms, SD = 254.25 ms) condition. *ACE* decreased between Trial Blocks 1 and 2. For the constant practice schedule condition, the decrease in *ACE* between trial blocks was found for the high and the low practice groups. The decrease in *ACE* between trial blocks was restricted to the high practice groups for the blocked practice schedule and to the serial practice schedule conditions. There was a small increase in *ACE* between trial blocks for the low practice–blocked group and the low practice–serial group. All other findings were not significant.

Discussion

Our purpose in the present experiment was to investigate the effects of practice schedule and amount of practice on GMP performance and parameter estimation in a multisegment timing task. We investigated contextual interference by having learners practice in either a serial or a blocked schedule three multiple-segment timing tasks that shared the same GMP. The inclusion of a constant practice condition allowed us to investigate the variability of practice prediction (Schmidt, 1975). The use of a transfer paradigm in which systematic changes were made in task characteristics across three tests provided the basis for an examination of predictions made by previous researchers concerning both variability of movement practice and contextual interference.

Parameter estimation, as reflected by *ACE* measures, and GMP performance, as reflected by *AE*(prop) measures, were more accurate during acquisition for the blocked and the constant practice schedule conditions than for the serial practice schedule condition. Increased practice led to greater accuracy in both parameter estimation and GMP performance for the blocked and the constant practice conditions. However, increased practice had little effect on either parameter estimation or GMP performance for the serial practice schedule condition.

Those findings were unexpected for two reasons. First, although task parameters changed frequently across trials for the serial practice schedule condition, the GMP did not. Second, the amount of practice with the GMP for all of the practice schedule conditions was three times greater for the high than for low practice conditions. We therefore expected that parameter estimation would be disrupted by the serial practice schedule but GMP performance would be unaffected. Specifically, our expectation was that parameter estimation would be less accurate for participants in the serial practice schedule condition than for those in the blocked and the constant practice schedule conditions but there would be no difference in GMP performance among the practice schedule conditions. Those findings indicate that some consistency in parameter values across practice trials is necessary for GMP performance (Lai & Shea, 1998, 1999).

The results of Posttest 1 showed that a constant or a blocked practice schedule is beneficial for GMP performance when a single task is to be performed in the same way as it was practiced. Hall and Magill (1995) proposed that variability of practice effects would be found when the same GMP governs the practiced tasks but that contextual interference effects would be found only when practiced tasks are governed by different GMPs. The findings for Posttest 1—that GMP performance was superior for the constant and the blocked practice schedules than for the serial practice schedule—were not consistent with those predictions.

According to the variability of practice prediction (Schmidt, 1975), performance should have been superior for the blocked and serial practice schedule conditions than for the constant practice schedule condition. According to Magill and Hall (1990; Hall & Magill, 1995) and Sekiya et al. (1994), the difference between the blocked and the serial practice schedule conditions should not have been significant because the tasks shared a common GMP. Furthermore, the superiority of the blocked over the serial practice schedule condition was in the opposite direction predicted for contextual interference effects (Magill & Hall, 1990). Wulf and Lee (1993) found inconsistent differences across trial blocks in GMP performance between random and blocked practice schedule conditions on an immediate retention test. Those findings, together with those of the present experiment, suggest that GMP performance across multiple tasks is sensitive to the practice schedule used. Moreover, the findings provide strong support for an advantage of a blocked practice schedule over a serial practice schedule for GMP performance.

A tentative explanation can be offered for the finding that GMP performance was superior for the constant and the blocked practice schedule conditions than for the serial practice condition. According to Lai and Shea (1998, 1999), increased response stability during acquisition as a result of a constant practice schedule enhances GMP performance. Stability would have increased in the present experiment because the parameters changed less frequently across trials for the constant and the blocked practice conditions than for the serial practice condition. The present findings reinforce those of Lai and Shea (1998), who reported a marginal benefit in GMP performance for a constant over a serial practice schedule condition. In addition, the present findings extend Lai and Shea's hypothesis to a blocked practice schedule for multiple tasks. The differences among practice schedule conditions for parameter estimation in the present experiment were not significant. That finding is consistent with Wulf and Lee's (1993) results for an immediate retention test, as well as for Lai and Shea's (1998) observations in a 24-hr delayed retention test. In those experiments, no practice schedule effects for parameter estimation were found. The nonsignificant differences for parameter estimation, together with the significant differences in GMP performance between the blocked and the serial practice schedule conditions in Wulf and Lee's, Lai and Shea's, and the present experiments, contradict the prediction of Sekiya et al. (1994) that those differences would be found for parameter estimation but not for general motor programming.

The results of Posttest 2, the same GMP transfer test, demonstrated that a variable practice schedule, as represented by blocked or serial practice schedules, is advantageous for GMP learning when task parameters must be adjusted. Thus, the variability of practice prediction garnered support from Posttest 2, same GMP transfer test: GMP performance was superior for both the blocked and the serial practice conditions than for the constant practice schedule condition. The finding that GMP performance was nearly equivalent for the blocked and the serial practice conditions is consistent with the prediction of Magill and Hall (1990; Hall & Magill, 1995) that contextual interference effects should not be present when the practiced tasks are governed by the same GMP.

The findings for GMP performance in the present experiment differed from those of Lai and Shea (1998), who found a beneficial effect for a constant over a serial practice schedule. The finding in the present experiment—that transfer to a task with the same GMP but different parameters adversely affected *AE*(prop) measures for the constant practice schedule condition—is noteworthy. *AE*(prop) measures should have been small and *ACE* measures should have been large if in that condition new parameters were not assigned to the formerly acquired GMP. However, *AE*(prop) measures were larger for the constant practice condition than for the blocked and the serial practice schedule conditions. The inability to preserve the relative timing structure in spite of a change in movement parameters introduces the possibility that those task characteristics might be linked for the constant practice schedule condition. There would be such a linkage if, in the constant practice schedule condition, the GMP and parameters were consolidated into a single unit that was unavailable for updating.

Support for the notion of consolidation of the GMP and parameters into one unit was obtained from the finding that increased practice enhanced GMP learning for the blocked and the serial practice schedule conditions but hindered GMP learning for the constant practice schedule condition. The interdependence of parameter estimation and GMP performance might be related to the way in which we provided KR in the present experiment. KR was given as the goal movement segment parameters along with the actual movement segment parameters. The learners therefore had to derive the correct GMP directly from the movement segment parameters. Lai and Shea (1998) interpreted their findings as evidence for the independence of the GMP and parameters (see also Wulf, Lee, & Schmidt, 1994; and Wulf, Schmidt, & Deubel, 1993). The manner in which they gave KR might have contributed to that independence.

In Lai and Shea's (1998) experiment, KR concerning total movement time was presented on all acquisition trials, and KR concerning movement segment proportions was provided on either 50% or 100% of acquisition trials. In comparison with the procedure used in the present experiment, their method of providing KR might have facilitated the learning of the GMP. The provision of the goal total movement time on all trials allowed the participants to easily determine the duration of individual movement segments by comparing segment proportions and the total movement time. That processing strategy would encourage the independent processing of GMP and parameters. It is interesting that Wulf and Lee (1993) provided KR in the same way as we did in the present experiment and found evidence consistent with that of the present experiment: that GMP and parameters are linked. Wulf et al. (1994) provided KR in the same way as did Lai and Shea (1998) and found evidence consistent with the independence of the GMP and parameters.

The results of Posttest 3, the different GMP transfer test, demonstrated that generalized motor program performance is superior for a serial as opposed to a blocked practice schedule when performance of a task is governed by a GMP that differs from the one that governs its acquisition. That finding is consistent with the contextual interference prediction of Magill and Hall (1990; see also Hall & Magill, 1995) and suggests that their prediction can be extended to cases in which practiced tasks are governed by different GMPs. In addition, parameter estimation was superior for the blocked and the serial practice schedule conditions than for the constant practice schedule condition. The transfer test findings extend Lai and Shea's (1998) earlier research to situations in which the GMP that governs a newly performed task differs from the one that governs earlier practiced tasks. The GMP findings did not support their prediction regarding the benefit of constant practice that promotes response stability for the GMP. However, the parameter estimation findings did provide support for Lai and Shea's proposal that parameter estimation benefits from variable practice schedules that disrupt response stability.

Taken together, those findings provide evidence that constant practice, variable blocked practice, and variable random practice are important for learning the invariant structure of the motor program. Constant practice enhances the performance of the motor program when exact reproduction of the movement program and parameters are specified or when task-specific movement performance is necessary. Variable blocked practice and variable random practice, however, enhance learning of the same and different motor programs, respectively. The learning of the invariant timing structure is further affected by the conditions of practice—specifically, the factors that affect response stability and variability in the response. Such conditions include changes in parameters and variations in the type of feedback provided to participants. The present experiment also raises the questions of the different mediating effects that amount of practice has on practice schedule effects and program versus parameter learning.

Finally, the present findings also have practical implications for the teaching of multisegment timing tasks. Specifically, they suggest that when practicing spatially constrained multisegment timing tasks, constancy and repetition in the practice context support the performance of the invariant structure or temporal rhythm of a specific movement. Variations in practice introduced by practicing new parameters within the same program or new motor programs, however, support the generalizability of GMP more than they do the generalizability of parameter estimation.

ACKNOWLEDGMENT

We thank James Cauraugh and Thomas S. Marzilli for their helpful suggestions in the preparation of this article.

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Submitted April 5, 2000
Revised March 7, 2001
Second revision July 20, 2001