The Effect of Self-Regulated and Experimenter-Imposed Practice Schedules on Motor Learning for Tasks of Varying Difficulty

Katherine M. Keetch and Timothy D. Lee

Research suggests that allowing individuals to control their own practice schedule has a positive effect on motor learning. In this experiment we examined the effect of task difficulty and self-regulated practice strategies on motor learning. The task was to move a mouse-operated cursor through pattern arrays that differed in two levels of difficulty. Participants learned either four easy or hard patterns after assignment to one of four groups that ordered practice in blocked, random, self-regulated, and yoked-to-self-regulated schedules. Although self-regulation provided no special benefit in acquisition, these groups showed the most improved performance in retention, irrespective of task difficulty. Although individual switch strategies for members of the self-regulated groups were quite variable, the impact of self-regulation on motor learning remained similar. These findings add to the growing body of literature suggesting that self-regulated practice is an important variable for motor learning.

Key words: contextual interference, performance-contingent practice, yoked controls

One goal of motor learning research is to identify factors that optimize the acquisition of motor skills, and in doing so, to better understand the underlying processes that influence the learning process. Although many factors have been shown to be important for motor learning, practice organization is a particularly powerful variable. One of the most frequently studied is the effect of random and blocked practice (commonly termed the “contextual interference” effect—Battig, 1979; Shea & Morgan, 1979). This effect reveals that individuals who practice in high levels of contextual interference (e.g., a random ordering of trials on different tasks) have inferior performance scores during acquisition compared to low levels of contextual interference (e.g., a blocked practice order in which all practice trials of one task are performed before any of another task). The effect of low vs. high contextual interference is reversed in retention, however (the random group is superior in performance compared to the blocked group). Therefore, although blocked performance results in short-term advantages in motor performance, random practice is actually more beneficial for long-term gains (i.e., better for learning). Shea and Morgan’s findings generated considerable interest, and researchers have subsequently replicated, extended, and theorized about these findings (for reviews, see Brady, 2004; Magill & Hall, 1990).

Theoretical arguments about the contextual interference effect suggest that blocked practice encourages an impoverished level of cognitive processing (for discussion see Lee & Magill, 1983, 1985; Shea & Zinn, 1983, 1988). This processing deficit should be especially strong when learning motor skills that are relatively simple in task difficulty. In contrast, tasks that have a higher level of difficulty would be expected to encourage greater cognitive processing, and this would be expected to be so despite of the impoverished level of processing promoted in a blocked practice order (Guadagnoli & Lee, 2004). Therefore, task difficulty is one of the variables expected to modify the amount of contextual interference experienced during practice.
and evidence exists to support this contention. For example, blocked and random groups in Albaret and Thon (1998) learned to draw geometrical patterns that differed in complexity, each pattern having either two, three, or four line segments. The typical contextual interference effect was found for those individuals who practiced the two- and three-segment patterns. However, the effect was not observed for those individuals who learned the four-segment pattern. The additional cognitive effort used by the blocked group in the acquisition of the most difficult task resulted in beneficial gains in long-term transfer, comparable to the random group.

The findings of Albaret and Thon (1998), and others, were conceptualized in a learning framework by Guadagnoli and Lee (2004). According to their Challenge Point framework, the effectiveness of various practice conditions depends on the interaction of a number of factors, including task difficulty and the characteristics of the individual (such as the skill level of the participant performing the task). Guadagnoli and Lee suggested that the learning environment is influenced by the nominal task difficulty of a motor task (the constant amount of task difficulty, regardless of who is performing the task and under what conditions it is being performed), and also by its functional difficulty (how difficult the task is to the individual performing it; how specific conditions influence the difficulty, etc.). Relating this concept to the contextual interference effect in particular, Guadagnoli and Lee suggested that blocked practice might be more effective for tasks with higher, compared to lower, nominal task difficulty. Conversely, random practice advantages may be greater for tasks of lower nominal task difficulty than for tasks with higher nominal difficulty. Furthermore, individuals with lower skill levels may benefit more from blocked practice, and random practice would be beneficial for more highly skilled individuals. In sum, the Challenge Point framework suggests that the individual is a critical factor in determining how to optimize practice-related factors.

Consideration for the individual as an active participant in the learning process has been demonstrated recently in research addressing the impact of self-regulation. Specifically, giving individuals control over their learning environment has been shown to have beneficial effects for motor learning. For instance, studies in which the learners decided when to receive KR (knowledge of results) revealed superior performance in retention and transfer tests compared to yoked controls that received KR at the same times, but in an experimenter-imposed schedule (e.g., Chiviacowsky & Wulf, 2002, 2005; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle, Kim, & Singer, 1995). Similar results have been found when participants self-regulated the option of when to use a physical guidance device (e.g., Wulf & Toole, 1999) and when to receive modeled information (e.g., Wrisberg & Pein, 2002; Wulf, Rautzach, & Pfeiffer, 2003).

Studies investigating the self-regulation of practice schedules, though limited in number, have produced findings similar to the above investigations. For example, Titze, Shea, and Romack (1993) examined the effects of a self-regulated practice schedule for a computer-based task that required participants to strike barriers in a particular sequence as quickly as possible. Titze et al. found that learners who were allowed to self-regulate their practice order performed equivalent to the blocked group during acquisition and also equivalent to the random group in retention. Moreover, both the self-regulated and random groups made fewer errors than the blocked practice group in retention. A limitation to this study, however, was the lack of a yoked control group (common in the self-regulated feedback research) in which each participant was assigned a practice order that matched an individual in the self-regulated group. In the absence of a yoked control group, the evidence from the Titze et al. study cannot rule out the alternative possibilities that the results were due to the benefits of self-regulated practice in general, or due to the specific practice schedules adopted by these particular learners. More recent studies by Wu and Magill (2004, 2005) found that a self-regulated schedule was superior to yoked control groups in the performance of golf putts or keypress sequences. These findings lend further support to the idea that a participant’s control over the practice schedule has a positive influence on learning.

Although the interactive effects of self-regulated practice for tasks of varying difficulty have not been investigated using motor skills, a recent study in verbal learning (Son, 2004) found that an individual’s perception of task difficulty determined how they chose to self-regulate practice. Participants memorized word-pair associations and were instructed that they could either have the same pairing presented again on consecutive trials (i.e., massed practice), or could choose to study that pairing again later in practice (i.e., spaced practice). Son found that participants chose to practice word-pairings perceived to be easy at a later time (i.e., practice was spaced), whereas word pairings judged to be difficult were practiced again sooner (i.e., practice was massed).

Given the findings in verbal learning by Son (2004), together with known effects of task difficulty on practice schedule effectiveness in motor learning (e.g., Albaret & Thon, 1998; Guadagnoli & Lee, 2004), the following investigation was carried out with two aims. The first aim was to examine how self-regulation affects the learning process relative to yoked controls and other experimenter-imposed schedules (random...
and blocked practice). The second aim was to assess how self-regulated strategies change as a function of task difficulty. We hypothesized that self-regulation would be advantageous for motor learning, particularly in retention. We also hypothesized that self-regulated strategies would change as a function of task difficulty. Specifically, we anticipated that individuals would switch between tasks less frequently during practice when the tasks were more difficult, and switch more frequently when the tasks were less difficult. In terms of the contextual interference effect, we hypothesized that blocked practice would not be detrimental for retention of the motor skills when the tasks were difficult, but that typical contextual interference effects would occur for the easy tasks (Guadagnoli & Lee, 2004).

Method

Participants

Ninety-six undergraduate students (age range: 18–28 years) from the McMaster University community participated in this study. Participants were assigned to one of eight different groups (n = 12), which differed in terms of the difficulty of the tasks performed (easy or hard) and the practice schedule used (e.g., blocked, random, self-regulated, or yoked). Assignment to groups was randomized, with the exception that gender within each group was approximately equal. All participants had self-reported normal or corrected-to-normal vision and were right-handed, with the exception of one left-handed participant in each group. The study was undertaken according to the university’s ethical guidelines. The participants, who were naive to the purpose of the study, gave informed consent before the experiment and received $10 (CDN) in compensation.

Apparatus and Task

Individuals sat in front of a standard desk that supported a 33 x 33 cm computer monitor (Samsung SyncMaster 700b Plus) with a keyboard (Microsoft Natural) and two-button laser mouse (Microsoft PS/2 Port) and pad. The task required a sequence of aim-and-click movements of the mouse to maneuver a cursor through a pattern displayed on the monitor. On each trial the monitor displayed a 4 x 4 array of squares (total size of the array was 19 x 19 cm; each square within the array was 3.8 x 3.8 cm; 1.3 cm spacing occurred on all sides). Each square within the array was either black or white. The participant’s task on each trial was to move the cursor from the square in the lower left corner of the array sequentially to four subsequent squares, stopping in each square only long enough to make a left or right mouse-button click. The goal was to perform the entire sequence as quickly as possible without making errors.

Task difficulty was defined by the arrangement of black and white squares within the array, as illustrated in Figure 1. The sequence was illustrated by red lines that attached adjacent squares. A white square required a left mouse-button press and a black square required a right mouse-button press. Pattern difficulty was established by two factors. First, the specific sequencing of right and left mouse buttons made each pattern more

![Illustration of pattern sequences](image)

**Figure 1.** Illustration of the pattern sequences to be learned. The four arrays in the upper half of the figure represent the “easy” patterns; the lower arrays represent the “hard” patterns.
or less difficult to complete quickly and error-free. The set of arrays in the top half of Figure 1 illustrates patterns that were relatively easy to perform quickly and without error, and the bottom portion of Figure 1 illustrates the hard patterns. Pilot testing confirmed that the easy patterns were performed significantly faster and with fewer errors than the hard patterns. Second, goal achievement was more or less difficult by requiring that the mouse be manipulated by the dominant limb for the easy patterns, and by the nondominant limb for the hard patterns. The software program E-Prime (version 1.0, Psychology Software Tools, Inc., Pittsburgh, PA, USA) was customized to initiate all stimulus displays and record the dependent measures of interest.

**Procedure**

All participants performed 128 practice trials of the four patterns to be learned (32 trials per pattern) at one level of task difficulty (see Figure 1). The primary difference between the groups was the schedule used to practice the set of patterns: blocked, random, self-regulated, and yoked-self-regulated (hereafter called “yoked”). The blocked group practiced all 32 acquisition trials of one pattern before any trials of another were completed (the order of patterns to be practiced was counterbalanced across participants). The random group’s practice schedule was randomized within blocks of 16 trials, such that four trials of each pattern were practiced within each block of 16 and no more than two trials of any pattern were practiced consecutively (cf. Shea & Morgan, 1979). The self-regulated group practiced the patterns in the order of their choosing. Pilot study results revealed that self-regulated participants tended to follow an “ABCD” ordering. Specifically, most individuals started with Pattern A, then B, and so on. Therefore, the pattern designation was changed across participants such that Pattern A was sometimes referred to as Pattern B, or C, or D. The specific assignment of letter designation to each pattern was completely counterbalanced across individuals within each of the groups according to a Williams square design (Williams, 1949). Participants in the yoked group were gender-matched to each of the participants in the self-regulated group and practiced the patterns in the identical order as their counterpart.

At the beginning of the first session, the "acquisition" phase, individuals were shown a series of instruction screens that described the task, including all of the different patterns to be learned, which the individuals were allowed to study for 30 s. Included in this information was a description of the feedback that was to be provided after every trial. This feedback consisted of three pieces of information: (a) movement time for the trial, (b) pattern accuracy (i.e., were the correct mouse buttons pressed in the correct order?), and (c) cursor accuracy (i.e., was the cursor inside the square when the mouse button was pressed?). This feedback screen was displayed for 5 s after each trial during the acquisition phase. Subsequently, an additional screen was displayed that informed individuals about how many trials remained for each pattern. Following this information the blocked, random, and yoked groups were instructed to press the space bar to advance to the next trial. However, the self-regulated group was asked, "Which pattern would you like to practice on the next trial? Pattern A = press a, Pattern B = press b..."

The keyboard button they pressed determined the pattern practiced next.

A trial started with a screen that displayed the upcoming pattern to be practiced (e.g., Ready, Pattern A). Following a 2-s exposure to this screen, individuals were required to place the mouse cursor into an initially red starting square in the bottom left corner of the array. This starting square was in the same location for each trial (bottom left square in array = first square of every target sequence; see Figure 1). In order for the pattern array to appear, participants needed to have the cursor correctly positioned in the starting square for 1 s. Consequently, after the 1-s homing period, a tone sounded and the pattern array appeared. Participants were instructed that they did not need to start their movement right away, but rather, to begin when they were fully prepared to complete the entire movement as quickly and accurately as possible. After the movement was completed, individuals viewed the screens that provided augmented feedback and information about the number of trials remaining for each pattern.

All participants completed two sessions. The acquisition session consisted of 128 practice trials in which participants were required to complete 32 trials of each pattern in their group-defined orders. It is important to note that although the individuals in the self-regulated group determined their order of practice trials, 32 trials per pattern were still required. Whenever the 32 trials of practice on a particular pattern had been exhausted, an option for further trials on that pattern was no longer available. The retention session, conducted after a 24-hr delay period, consisted of four trials of each previously practiced pattern, performed in a random order with no augmented feedback.

**Dependent Measures**

Movement time, pattern error, and cursor error data were recorded on each trial. Movement time was the duration lapsed from the button press in the first square until the button press in the last square. A pattern error was defined as an incorrect button press (e.g., pressed the left mouse-button instead of the right button). A cursor error was a button press that occurred when the cursor was outside the appropriate square in the pattern.
As each pattern consisted of five squares, a maximum of five pattern errors and five cursor errors could occur during each trial. Note, however, that pattern accuracy data provided no group-related differences in acquisition or retention, so will not be discussed further.

The number of switches that occurred during acquisition was considered an important measure of the scheduling strategies for the self-regulated group. A switch was recorded whenever different patterns were performed on two consecutive trials during the practice phase (e.g., pattern A was performed on trial n and pattern C on trial n + 1).

Data Analysis

Acquisition data for movement time and cursor errors were analyzed using a 2 (task difficulty: easy, hard) x 4 (group: blocked, random, self-regulated, yoked) x 8 (blocks of 16 trials, 4 trials of each pattern) mixed analysis of variance (ANOVA), with block as a repeated measure. Retention data for each dependent measure were also analyzed using a 2 (task difficulty: easy, hard) x 4 (group: blocked, random, self-regulated, yoked) x 2 (block: last acquisition block, retention block) mixed ANOVA, with block as a repeated measure. Preliminary analyses of movement time data revealed some large departures from homogeneity of variance, particularly so when comparing the performance of the easy versus hard tasks. Therefore, a natural logarithm transform was performed on the movement time data before statistical analyses.

To examine how the switch patterns of the self-regulated groups changed over acquisition as a function of task difficulty, the switch data were submitted to a 2 (task difficulty: easy, hard) x 2 (switch frequency: switched rarely, switched often) x 8 (block) mixed ANOVA, with block as a repeated measure. The switch frequency subgroup factor was added after both pilot and present data revealed considerable individual differences in the strategies adopted by the self-regulated participants. Specifically, some chose to switch often while others chose to switch very rarely. Cut-off for switch-frequency-subgroup divisions was determined based on pilot study results—individuals who chose to switch “rarely” did so, on average, for less than 25% of the trials. Therefore, for present purposes, inclusion in the switch-rarely group or switch-often group was defined as switching less than 25% of the trials and switching greater than 25% of the trials, respectively.

Two additional analyses were conducted to examine the observed strategies and subsequent performances of the self-regulated groups. First, an analysis was conducted to examine what effect switching had on performance for the self-regulated groups. Specifically, we attempted to assess whether there was a difference in performance of the switch frequency subgroups (i.e., those who chose to switch rarely versus those who chose to switch often). Therefore, movement time and cursor error data were submitted to a 2 (task difficulty: easy, hard) x 2 (switch frequency: switch rarely, switch often) x 8 (acquisition block) or [2 (retention block)] mixed ANOVA, with block as a repeated measure.

A second analysis was conducted to examine why those in the self-regulated groups who chose to switch often did so during acquisition. In a self-regulated feedback study, Chiviacovsky and Wulf (2002) found that participants tended to request feedback after “good” trials. Here, we were interested to assess performance on trials where a decision was made to switch to a new pattern for the subsequent trial compared to the performance on the trial before this decision was made (i.e., same pattern practiced on the subsequent trial). Although participants were not explicitly asked why they chose to switch to a new task, our hypothesis was that if individuals were basing their decision to switch in a performance-contingent manner (i.e., after good trials), then better performance (e.g., faster movement times, increased accuracy) was expected on the switch trial (n) compared to the trial before the switch (n - 1) for the self-regulated group. In contrast we did not expect this same pattern of results for the yoked participants, even though these individuals had the identical practice schedule. To test this hypothesis, the dependent measures were submitted to a 2 (task difficulty: easy, hard) x 2 (group: self-regulated, yoked) x 2 (trial: trial n, trial n - 1) mixed ANOVA, with trial as a repeated measure. In this analysis, performance data of the trial factor always came from the same pattern. All significant effects and interactions were examined using Tukey’s post hoc procedures where appropriate with α set at p < .05. Significant effects were augmented with measures of η².

Results

Movement Time

Acquisition. Analysis of the movement time data revealed main effects for task difficulty, F(1, 88) = 208.64, p < .01, η² = .703, and block, F(7, 616) = 216.43, p < .01, η² = .711. Participants performed the easy tasks (1,005 ms) in less time than the hard tasks (1,820 ms), and improved their movement times in each block over acquisition, with reductions in movement time no longer significant after Block 6.

There were also significant interactions between task difficulty and group. F(3, 88) = 4.63, p < .01, η² = .136; task difficulty and block. F(7, 616) = 2.70, p < .01,
η^2 = .03; and group and block, F(21, 616) = 4.67, p < .01, η^2 = .137. Post hoc analyses revealed that for the easy tasks, the self-regulated group (1,112 ms) was significantly slower than the yoked group (869 ms), with the random (978 ms) and blocked (1,060 ms) groups’ performance intermediate but not significantly different from each other or the other groups. For the hard tasks, the blocked group (1,565 ms) was significantly faster than both the self-regulated (1,911 ms) and yoked (1,914 ms) groups, which were not statistically different from each other or the random group (1,889 ms).

Additionally, we performed *a priori* planned comparisons to examine the separate effects of contextual interference and self-regulation in these data. The left side of Figure 2 illustrates the means for the blocked and random groups. The filled symbols represent performance on the easy tasks; the unfilled symbols represent the hard tasks. For the easy tasks, statistical analyses revealed no differences between the random and blocked groups, although better performance of the random group just failed significance at Blocks 5 and 7 (p = .06). For the hard tasks, the random group performed significantly poorer than the blocked group on Blocks 1, 2, 3, 4, 5, and 7. The right side of Figure 2 illustrates the means for the self-regulated and yoked control groups. For the easy patterns (filled symbols), the yoked groups performed faster than the self-regulated groups on each acquisition block after Block 1. No significant differences were found at any of the blocks for the hard patterns (unfilled symbols).

**Retention.** Main effects were found for task difficulty, F(1, 88) = 193.77, p < .01, η^2 = .688, and block, F(1, 88) = 29.81, p < .01, η^2 = .241. Participants who practiced the easy tasks remained significantly faster in retention compared to those who practiced the hard tasks, and movement times were longer in retention compared to the last block of acquisition overall. There was also a significant interaction between task difficulty and group, F(3, 88) = 4.60, p < .05, η^2 = .136, as well as a significant interaction of group and block, F(3, 88) = 18.19, p < .01, η^2 = .371. Post hoc analysis of these interactions revealed that for the easy tasks, the blocked group (1,046 ms) was significantly slower than the yoked group (801 ms), while the random (900 ms) and self-regulated (959 ms) groups fell intermediate but were not significantly different from each other or the other groups. There were no significant group differences in movement time retention performance for those who practiced the hard tasks (blocked = 1,503 ms; random = 1,704 ms; self-regulated = 1,742 ms; yoked = 1,799 ms).

Of most interest was the interaction of group and block (see Figure 2). Post hoc analysis of this interaction revealed that the blocked, random, and yoked groups all significantly *increased* movement time performance from the last block of acquisition to retention. In contrast, the self-regulated group significantly *decreased* movement time in retention compared to the last block of acquisition performance. Performance in the last block of acquisition revealed that the self-regulated group had significantly slower movement times than all the other groups, which were not different from each other. However, in retention, the self-regulated group was significantly faster than the blocked group, with the random and yoked falling intermediate but not significantly different from each other or the other groups. No other effects or interactions were significant.

**Cursor Errors**

**Acquisition.** Analysis of cursor error data revealed main effects for task difficulty, F(1, 88) = 7.34, p < .01, η^2 = .077, and block, F(7, 616) = 9.50, p < .01, η^2 = .1. Participants who practiced the hard tasks committed more cursor errors than those who practiced the easy tasks. More cursor errors were committed in Blocks 7–8 compared to Blocks 1–5. There were also significant interactions between task difficulty and group, F(3, 88) = 3.07, p < .03, η^2 = .095; group and block, F(21, 616) = 2.28, p < .01, η^2 = .072; as well as task difficulty, group, and block, F(21, 616) = 1.58, p < .05, η^2 = .051.

Similar to the movement time data in acquisition, we performed planned comparisons to examine contextual interference and self-regulation effects over trials for the easy and hard patterns. The left side of Figure 3 illustrates the cursor errors for the random and blocked groups. No differences were observed for any of the acquisition blocks when performance was compared on the easy patterns (filled symbols). However, for the hard patterns (unfilled symbols), the blocked group

---

**Figure 2.** Movement time results for all eight practice groups across acquisition and retention blocks.
had significantly more errors than the random group on Blocks 1, 3, 4, 6, and 7. The right side of Figure 3 illustrates the self-regulated and yoked group means. No differences between the groups for any of the blocks were observed for the easy patterns (filled symbols). For the hard patterns however, (unfilled symbols), the self-regulated group had significantly more cursor errors than the yoked controls on Blocks 6 and 8.

Retention. This analysis revealed a main effect of block, $F(1, 88) = 4.12, p < .04, \eta^2 = .045$ — more errors were made in the last block of acquisition trials than in retention. There were also significant interactions of task difficulty and group, $F(3, 88) = 3.40, p < .02, \eta^2 = .104$, and group and block, $F(3, 88) = 5.29, p < .01, \eta^2 = .133$. Post hoc analysis of the task difficulty x group interaction indicated that there was no difference in cursor error rates between the groups who performed the easy tasks; however, the blocked group committed more cursor errors than the yoked group when the hard tasks were performed, with the random and self-regulated groups intermediate and not significantly different from each other or the other groups. The group x block interaction revealed that cursor errors for the blocked, random, and yoked groups remained consistent from the last block of acquisition to retention; however, the self-regulated group significantly decreased cursor error rates in retention. Furthermore, this trend was apparent in retention for both task difficulties (see Figure 3).

Pattern Switches

Due to the predetermined schedule of task orders, the random group switched an average of 13.5 times per block of 16 trials for the easy tasks and 13.6 times per block for the hard tasks. Of course, switches occurred rarely for the blocked group—one at the completion of every 32 trials (or an average of 0.5 times per block of 16 trials). Because the blocked and random groups received experimenter-imposed practice schedules there was no between-participant variation in the number of switches between patterns undertaken during practice, hence these groups are excluded from ANOVA.

Participants in the self-regulated groups revealed considerable between-participant variation in the total number of switches made during practice—some chose to switch often, others rarely. For the group that practiced the easy patterns, a subgroup of 7 participants made between 0.5 and 2.1 mean number of switches per block. The remaining 5 participants switched much more frequently, between 5.0 and 14.6 times per block. For the group that practiced the hard patterns, a subgroup of 7 participants made between 0.5 and 2.8 mean number of switches; the remainder switched, on average, between 4.6 and 11.0 times per block. An analysis of these switch frequency data for these self-regulated subgroups across blocks revealed main effects for subgroup, $F(1, 20) = 60.64, p < .01, \eta^2 = .752$, and block, $F(7, 140) = 2.47, p < .02, \eta^2 = .110$, as well as a significant interaction between task difficulty, subgroup, and block, $F(7, 140) = 3.40, p < .01, \eta^2 = .145$. The means related to the interaction are illustrated in Figure 4. Post hoc analyses revealed no differences between the subgroups that switched rarely, either across blocks or for each of the task difficulties (left side of Figure 4). However, for the subgroups that switched frequently, those who practiced the easy tasks switched significantly more
often both early and late in practice (i.e., on Blocks 1, 7 and 8) compared to those participants who practiced the hard tasks (right side of Figure 4).

**Self-Regulated Switch Frequency Subgroups.** An analysis of movement time was conducted to examine the possibility that the beneficial effect of self-regulation occurred specifically because of switching strategies (i.e., the performance of one of the self-regulated switch frequency subgroups). Analysis of movement time data revealed main effects of task difficulty, $F(1, 20) = 45.40, p < .01$, $\eta^2_p = .695$, and block, $F(7, 140) = 34.94, p < .01$, $\eta^2_p = .691$, in acquisition but no effects or interactions with the switch frequency factor. Thus, no differences in acquisition movement time performance existed between those who switched frequently and those who switched rarely. Retention data analysis revealed main effects of task difficulty, $F(1, 20) = 53.15, p < .01$, $\eta^2_p = .725$, and block, $F(1, 20) = 10.71, p < .01$, $\eta^2_p = .362$, again, with no significant effects involving switch frequency. Analysis of cursor errors did reveal a significant Task Difficulty x Switch Frequency x Block interaction, $F(7, 140) = 3.19, p < .01$, $\eta^2_p = .13$, in acquisition. Post hoc analysis revealed that there were no differences between switch frequency subgroups for those who practiced the easy tasks. However, for those who practiced the hard tasks, the individuals that chose to switch more frequently made fewer cursor errors on Block 3 and more errors on Block 0 than those who chose to switch less frequently. There were, however, no significant effects or interactions with switch frequency subgroup or task difficulty in retention.

**Switching Strategies.** An analysis was conducted to examine whether the self-regulated groups that switched often were using a performance-contingent strategy for making their decision to switch. Specifically, had trials that were followed by a decision to switch been performed better (i.e., faster movement times, less error) than trials that were not followed by a decision to switch? The movement time analyses suggested so. Movement time analysis revealed a main effect for task difficulty, $F(1, 16) = 86.21, p < .01$, $\eta^2_p = .843$, as well as a significant interaction of group and trial, $F(1, 16) = 4.62, p < .05$, $\eta^2_p = .224$. The interaction revealed that movement times on trials that were followed by a switch (n) were significantly faster (1,565 ms) than the trials prior to the switch (n-1) for the self-regulated groups (1,604 ms), while there was no difference between these trial types for the yoked groups (1,431 vs. 1,438 ms). Cursor error analysis did not reveal any significant findings.

**Discussion**

The experiment reported here was designed to examine the effects of self-regulated practice schedules on motor learning as a function of task difficulty. It was hypothesized that self-regulation would reveal beneficial effects during acquisition, but most importantly, for retention. Following the lead of Son (2004), it was also hypothesized that self-regulation strategies might change as a function of task difficulty; specifically, less frequent switching was expected for the set of hard tasks compared to the easy tasks. Moreover, based on the Challenge Point framework (Guadagnoli & Lee, 2004), we hypothesized that a typical contextual interference effect would be demonstrated between the blocked and random groups for the easy tasks, but that blocked practice would not be detrimental to retention performance for the more difficult tasks.

**Effects of Self-Regulation**

The results of the present experiment partially replicated previous findings (e.g., Titmer et al., 1993; Wu & Magill, 2004, 2005), that allowing individuals to self-regulate their practice schedules enhanced motor learning. We found that individuals in the self-regulated groups showed continued improvement in movement time and cursor accuracy performance following a 24-hr delay. This beneficial improvement from the practice trials into retention contrasted sharply to the blocked, random, and yoked groups, which all showed decrements in motor performance in retention. The benefits of self-regulation were not evident, however, until retention, as performance of the self-regulated groups was actually inferior to the other groups in acquisition. This finding does not strictly contradict previous self-regulation studies (e.g., Janelle et al., 1995, 1997; Wulf et al., 1999, 2005), where the strongest effects of self-regulation became apparent at the time of retention/transfer with little group differences during acquisition.

**Effects of Task Difficulty on Self-Regulation Strategies**

The beneficial effects of self-regulation emerged irrespective of the different strategies adopted for tasks of differing difficulty. Those who practiced the easy tasks switched more frequently during practice than those individuals who practiced the hard tasks. This was most readily apparent when individuals were divided into switch frequency subgroups. Specifically, there were no differences in the number of switches between patterns for those who switched rarely, irrespective of task difficulty. However, for those who chose to switch more frequently, members of the self-regulation group who practiced the easy tasks switched more often early and late in practice compared to those who practiced the hard tasks.
There were a number of different strategies adopted by individuals within each of the self-regulated groups for both task difficulties, and yet, self-regulation benefits did not change as a function of the strategy. The amount of switching for the self-regulated groups fell intermediate to the blocked and random groups on the average. However, some individuals in the self-regulated groups chose to switch often while others chose to switch rarely. When the performance of these subgroups was analysed, we found that the beneficial effects of the self-regulated groups did not occur specifically because of the performance of one of the switch frequency subgroups, as there were no significant differences between the switch frequency subgroups in acquisition and retention for movement time and no differences in retention for cursor errors. The advantage of self-regulation in learning was not due to the number of switches between patterns during practice. Combined with the finding that the beneficial effects of self-regulation shown in retention occurred in both self-regulated groups, irrespective of the level of difficulty of performance and the switch strategy utilized, these collective results suggest that the self-regulation advantage may be due to benefit afforded by having a certain amount of control of the learning environment.

**Effects of Task Difficulty**

Another aim of this study was to investigate how all group performances were influenced by task difficulty. Task difficulty did have differential effects on group performance in acquisition and retention. Acquisition performance of all groups on the easy task was similar, with only the self-regulated group being significantly slower than the voked group. Perhaps the easy tasks in general were too simple to elicit differences in performance of the groups, with the exception of the self-regulated group, who may have generated more cognitive effort during acquisition with having to continually and actively make decisions about their practice structure. Conversely, the other groups may have employed less cognitive effort associated with performance of these easy tasks because the practice schedule was imposed on them, and so, may have been less cognitively demanding in acquisition. When the hard tasks were practiced, on the other hand, the blocked group performed significantly faster than the other groups. Blocked-practice superiority in acquisition is not surprising, as this is a tenet of the traditional contextual interference effect. It should be noted, however, that cursor error scores were higher for this blocked group in acquisition, so some speed-accuracy trade-offs may have contributed to this result.

Task difficulty also had a differential effect on group performance in retention. Specifically, the blocked group was the slowest in retention of those who practiced the easy tasks. This finding is consistent with the contextual interference effect and previous findings involving self-regulated practice (e.g., Titz et al., 1993). There were no significant group differences in movement time retention performance for those who practiced the hard tasks, although the self-regulated group did significantly decrease movement time in retention compared to the other groups. The lack of difference between the blocked and random groups, in particular for the hard tasks, is consistent with predictions made by the Challenge Point framework (Guadagnoli & Lee, 2004), suggesting that blocked practice may be more beneficial for motor learning if the task is sufficiently difficult to cognitively challenge the individual during the learning process. The blocked group that practiced the hard tasks actually maintained the fastest movement time performance overall in retention, without trading-off accuracy (i.e., they did not make significantly more errors in retention compared to acquisition). This finding contrasts with typical contextual interference literature and reveals that optimal practice scheduling should be based on factors such as the characteristics of the task (e.g., difficulty) as well as the individual performing the task, as suggested in the Challenge Point framework. The added finding that different schedules (i.e., switching frequently vs. switching less frequently) yielded the same result (i.e., increasing motor learning) in the self-regulated groups indicates that the individual is an integral component of the learning process. Taken together, these findings suggest that practice schedules should be organized to optimize motor learning on an individual-to-individual basis. The predictions laid out in the Challenge Point framework, in conjunction with self-regulation manipulations, merit further research.

**Why Switch During Self-Regulated Practice?**

Current research has begun to offer explanations of the mechanisms that underlie the self-regulation effect. One such factor is whether or not individuals base self-regulating decisions on their performance. Chiatossky and Wulf (2002) compared the effects of self-regulated feedback to a voked control group for a sequential-timing task. These researchers administered a questionnaire after the practice phase to try to determine when participants chose to receive feedback. Interestingly, 67% of the self-regulated group reported that they asked for feedback after they believed that their performance on the previous trial had been good. Furthermore, 73% specifically did not request feedback when they believed that they had performed poorly. As well, the voked participants, who had no choice in their schedules of feedback, often reported that they did not
receive feedback when they would have preferred, with most suggesting that they too would have preferred feedback after "good" trials. To measure whether individuals' self-reports of receiving feedback after good trials was accurate, these researchers compared performance on feedback trials versus no-feedback trials between the groups. For the self-regulated group, Chiviacoswky and Wulf found that error rates were lower on trials for which they requested augmented feedback than trials for which feedback was not requested, whereas the opposite was true for the yoked group. In addition, error scores were lower for the self-regulated group compared to the yoked group on feedback trials, with no differences between the groups on no-feedback trials (Chiviacoswky & Wulf, 2002).

A similar analysis was conducted to examine whether individuals were using a performance-contingent strategy for making their decision to switch in the present study (i.e., perhaps they were switching after "good" trials). We found that movement times of switch trials were significantly faster than the trial before the switch for the self-regulated group, whereas there was no difference between trial types for the yoked groups. The same trend occurred for cursor errors. These results are, in general, similar to the findings of Chiviacoswky and Wulf (2002) and suggest that individuals may base their decision to switch on performance-related factors, and this may be an effective strategy for motor learning. Specifically, this study revealed that individuals may set criteria for themselves to decrease movement time (at least from the previous trial) before allowing themselves to switch.

It is evident that individuals may have been using performance-contingent goals or strategies for their switch decisions. We also know, however, that performance-contingent switching is not solely responsible for the benefits of self-regulation in this study. Recall that no differences between switch frequency subgroups were found in acquisition or retention when comparing those individuals who chose to switch rarely with those who chose to switch often. If these individuals who switched more often who were predominantly responsible for the beneficial effects of self-regulation, then one would predict that these individuals would do better in acquisition and retention compared to the self-regulated participants who switched less frequently. Instead, there were no differences between subgroups. So, although self-regulation may allow for the use of performance-contingent strategies, the benefit of self-regulation may be a more general effect.

Findings from the present study and previous studies (Chiviacoswky et al., 2002, 2005) support the notion that self-regulation may be effective because it provides learners the opportunity to organize their learning environment in a manner that is contingent on their own performance. Individuals may be able to set incremental criteria or goals to be achieved before continuing to a new element of the task. But this is not the whole story of self-regulation. In general, we found that self-regulation was effective for motor retention. However, when analyses were conducted on the self-regulated groups that were split into those who switched frequently and those who choose to switch less frequently, there were no significant differences in retention performance. This finding suggests that it may be self-regulation in general and not the control of a specific aspect of the learning context that may be beneficial.

The study of self-regulation in motor learning is in its early stages, and considerable information needs to be acquired regarding how individuals choose to structure their learning environment, how the nature of the task and its relevance to the learner influence strategies, how the nature of an individual's experience influences practice-related decisions, and so on. Clearly, this research area holds promise for theoretical and practical advances in our understanding of motor learning processes.

References


Authors’ Notes

This research was supported by a graduate fellowship and operating grant awarded to the authors by the Natural Sciences and Engineering Research Council of Canada. We thank Luc Tremblay and Steve Hansen for their programming assistance. Please address all correspondence concerning this article to Katherine Keetch, Department of Kinesiology, McMaster University, 1280 Main Street West, Hamilton, ON, Canada L8S 4K1.

E-mail: keetchkm@mcmaster.ca