The Effects of Practice and Delay on Motor Skill Learning and Retention

Tal Savion-Lemieux

A Thesis

in

The Department

of

Psychology

Presented in Partial Fulfilment of the Requirements
For the Degree of Master of Arts at
Concordia University
Montreal, Quebec, Canada

August 2003

National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisisitons et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 0-612-83827-7
Our file Notre référence
ISBN: 0-612-83827-7

ABSTRACT

The Effects of Practice and Delay on Motor Skill Learning and Retention

Tal Savion-Lemieux

The present study assessed the effects of amount of practice and length of delay on the learning and retention of the temporal motor sequence task (TMST). Participants learned to reproduce ten-element visual sequences by tapping in synchrony with the stimulus. Participants were randomly assigned to a varied-practice condition (n = 28) or a varied-delay condition (n = 40). Participants in the varied-practice condition received either 1, 3, or 6 blocks of practice on the TMST, on each of five consecutive days, followed by a fixed 4-week delayed-recall. Participants in the varied-delay condition received 3 blocks of practice on the TMST, on each of five consecutive days, followed by a varied delayed-recall of either 3 days, or 2, 4, or 8 weeks. Learning was assessed by changes in accuracy, response variance, and percent response asynchrony. Results showed that amount of practice had no significant effects on learning and retention of the TMST, suggesting that minimal amounts of practice spread over several days are sufficient to induce long-term memory of a motor skill. Delay appeared to differentially affect retention of the TMST, as length of delay influenced response accuracy, delay affected response synchronization, and neither delay nor length of delay had effects on response variance. These results indicate that different aspects of a motor skill are stored in independent but parallel systems. We propose that level of proficiency, rather than amount of practice or length of delay, is the critical factor affecting motor skill learning and retention.

Acknowledgements

First and foremost, I would like to extend my warmest thanks and appreciation to my supervisor, Dr. Virginia Penhune, for her guidance, help, and encouragement on this research project. In the past two years, I have learned many things from Virginia, such as to always stay positive, keep smiling (even after spending endless days at the lab), have fun while writing my discussion, and enjoy a piece of chocolate when all else fails.

I would also like to thank the members of my thesis committee, Dr. Karen Li and Dr. Adam Radomsky, for making my defence an exciting, thought-provoking, and rewarding experience.

My greatest appreciation goes to the members of the Penhune lab for their valuable help and support. I would like to thank John Connolly, whom I dearly miss, for his cheerful presence, his sense of humour, and assisting me in the testing of participants. I would also like to thank Donalad Watanabe for his valuable help on this project, for his assistance in data collection, as well as for bringing "music" to the lab. I would like to extend my thanks to Alison Simioni and Jack Lapidus, for their commitment to the lab. And, finally, my deepest thanks go to my "lab partner", Clarisse Longo dos Santos, for her much cherished friendship and support.

To my friends, you know who you are, I have appreciated knowing that you were behind me every step of the way. Andy, thanks for your continuous encouragement and love; it really meant a lot to me. Yolaine and Yohan, thanks for being true friends and bringing me iced cappuccinos in times of need. Sophie, thanks for reading through multiple drafts of my thesis, as well as for being an amazing study and sushi partner.

Finally, Myriam, Oz, Thierry, Sophie, Yolaine, Yohan, and Ariel, thank you for travelling five consecutive days to Concordia to participate in my study.

Lastly, my deepest appreciation goes to my family and my "extended family" (Kara Olineck and Naomi Grunzeweig) for their unending support and love, as well as for standing by me every step of the way. Particularly, I would like to thank my "buddies", Kara and Naomi, for their invaluable friendship. Without them, and many trips to Starbucks, Winners, HMV, and AMC, this experience would not have been the same. I would also like to thank my mom for giving me everything I ever wished for, my dad for giving me his undevoted time and attention (and always picking up Kara, Naomi, and I, with a smile, late at night), and my brother Ariel, for finally taking interest in what I am doing.

This research was supported by a grant from the Natural Sciences Research Council of Canada to Dr. Virginia Penhune. While conducting this research, I was supported by a scholarship from the Centre for Research in Human Development.

Table of Contents

List of Figures

List of Appendixes

Throughout life, a vast array of motor skills are learned and retained. While certain skills such as walking and talking are largely innate, others such as playing the saxophone and swinging a baseball bat are mainly acquired through continuous repetition and experience. Motor skill learning, also referred to as procedural learning (Hikosaka, Nakahara, Rand, Sakai, Lu, Nakamura, Miyachi, & Doya, 1999), is the process by which motor skills become effortlessly performed through practice (Willingham, 1998). For instance, when a child first learns to ride a bicycle, his movements are unsteady. After an entire summer of practice, he has learned to ride the bicycle without falling. But, when the weather gets colder, the child has to store his bicycle away for the winter. The following summer however, it takes a couple of days of practice before he can ride as well as he did last summer. Thus, once a skill is well practiced, it can be retained for months and even years (Karni & Sagi, 1993). Since motor skills are ubiquitous in our daily life, considerable effort has been made to determine the principal factors affecting their learning and retention. Such investigations are necessary as these findings impact different domains, including sports and music training, as well as physical and occupational rehabilitation (Schmidt, 1991). The focus of the present investigation was to look at the effects of amount of practice and length of delay on the acquisition and retention of a temporal motor sequence task (TMST). Participants practiced the TMST for five consecutive days, followed by a varied delayed-recall session. In the varied-practice condition, amount of practice but not length of delay was modulated. In the varied-delay condition, length of delay but not amount of practice was modulated. We hypothesized that amount of practice would influence the learning and retention of the TMST. Furthermore, we expected length of delay to affect retention of the TMST.

Three stages of motor skill learning have been identified, corresponding to distinct points in the pattern of incremental changes in performance across sessions of practice (see Doyon & Ungerleider, 2002; Karni, Meyer, Rey-Hippolito, Jezzard, Admas, Turner, & Ungerleider, 1998, for reviews). The first stage occurs within the initial session of practice, where rapid improvements in performance are observed (Karni & Sagi, 1993; Toni, Krams, Turner, & Passingham, 1998; Van Mier, Tempel, Perlmutter, Raichle, & Petersen, 1998). The second stage, referred to as consolidation, occurs following the initial practice session. In this stage, significant improvements in performance are observed following a period of rest, of greater than four hours, with no further practice (e.g., Karni & Sagi, 1993; Muellbacher, Ziemann, Wissel, Dang, Kofler, Facchini, Boroojerdi, Poewe, & Hallett, 2002; Shadmehr & Brashers-Krug, 1997). Several experiments have also demonstrated that a night of sleep further improves performance on a recently acquired skill (Maquet, Schwartz, Passingham, & Frith, 2003; Stickgold, Hobson, Fosse, & Fosse, 2001). In fact, a recent study showed that the amount of time spent in stage 2 non-rapid eye movement (NREM) sleep, especially in the last quarter of the night, is particularly important for consolidation of a skill (Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002). The third stage of motor skill learning occurs throughout the remaining practice sessions (days or weeks), where slower and more gradual gains lead to a plateau in performance (e.g., Karni, Meyer, Jezzard, Adams, Tuner, & Ungerleider, 1995). Finally, once a skill is well-learned, few declines in performance are noted, even after extended delays with no additional practice (e.g., Penhune & Doyon, 2002; Karni & Sagi, 1993).

Support for separable stages of motor skill learning comes from experiments in animals and humans showing that different brain regions are involved at different phases of learning (see Van Mier, 2000, for review). A number of human brain imaging studies have shown that the cerebellum is primarily active during the early stage of learning (Doyon, Owen, Petrides, Sziklas, Evans, 1996; Penhune & Doyon, 2002), while the striatum is involved in consolidation (Penhune & Doyon, 2002) and the later stage of learning (Doyon et al. 1996; Grafton, Woods, Mike, 1994). Finally, the primary motor cortex (Penhune & Doyon, 2002; Karni et al., 1995) and cerebellar nuclei (Hikosaka, Nakamura, Sakai, & Nakahara, 2002) have shown to be active at the delayed-recall or retrieval stage. In a recent study done in our laboratory (Penhune & Doyon, 2002), a dynamic network of cortical and subcortical structures has shown to be differentially activated during the acquisition and retention of the TMST. We proposed that the cerebellum is important in adjusting movement kinematics during the early phase; the basal ganglia is involved in automatization of movements; and, the motor, primary motor, and parietal cortices are responsible for storing motor representations of the temporal motor sequence. Based on these hypotheses, we predicted that motor cortical activity would be modulated by changes in the amount of practice on the task, or in the length of delay before recall. Thus, the aim of the present behavioural experiment is to look at behavioural changes related to the amount of practice and length of delay before recall on the learning and retention of the same temporal motor sequence task.

A wide range of behavioural experiments have explored the effects of practice on performance at different stages of motor skill learning. Studies examining early learning have consistently shown rapid improvements in performance within a single session of training, as evidenced by significant decreases in reaction time and increases in response accuracy. For example, participants exhibited skilled performance on a novel maze tracing task after only a 10-minute practice session (Van Mier et al., 1998). Furthermore, findings have demonstrated that spacing practice intervals with periods of rest significantly improved performance within the first day of learning, compared to massing practice with no periods of rest (Bourne & Archer, 1956; Shea, Lai, Black, & Park, 2000). Participants who received 60-second rest periods after completion of 30-second work trials on a pursuit rotor tracking task performed significantly better than participants who received no rest, or 15-, 30-, or 45-second rest periods (Bourne & Archer, 1956). Experiments investigating the effects of practice on consolidation have shown similar findings, namely that a period of rest of greater than four hours, or a night of sleep, results in improvements in performance when comparing performance on the first learning session to performance on the second session (Karni & Sagi, 1993; Shea et al, 2000; Walker et al., 2002). Spacing two practice sessions either 20 minutes apart or 24 hours apart resulted in overall enhanced performance on a continuous balance task. However, the 24-hour group tended to show more proficient performance on the second session, as evidenced by lower root mean square error (Shea et al., 2000). Likewise, participants who were tested in the evening on a sequencing task and re-tested 12 hours later after a night of sleep improved significantly, compared to participants who were tested in the morning and re-tested later during the same day (Walker et al., 2002). Spacing practice sessions over several days or weeks, beyond the first and second days of practice, also results in enhanced performance; however, improvements in this later stage of learning are slower and more gradual (Karni et al., 1995; Karni & Sagi, 1993; Shea et al., 2000), suggesting that day 1 to day 2 improvements may simply reflect the most dramatic step of an ongoing process. After a critical amount of training however, performance reaches a plateau; performance is either at ceiling or changes are very small (Karni, 1996; Karni et al., 1998; Welford, 1987). For example, beyond 3 weeks of 10-20 minutes of daily practice on a simple sequential finger opposition task, little change in accuracy and speed of movement were noted (Karni et al., 1995). Taken together, these results suggest that practice spaced across days of training result in early rapid changes in average performance, followed by later more gradual changes. This pattern of findings is consistent with the law of practice whereby practice follows a relationship where enhancements in performance are directly related to how much improvement remains in the test (Schmidt, 1991). When the task is novel, there is a greater opportunity for improvement however, the opportunity decreases as learning increases (Schmidt & Lee, 1999; Welford, 1987). Interestingly, no studies to date have looked at the effect of different amounts of practice on the acquisition of a motor skill across several days of practice. Therefore, the first goal of this study was to look at the effects of amount of practice on motor skill learning and retention.

Another important component of motor skill learning is retention of the skill after a period of delay with no practice. Retention refers to the relative task performance after the delay. The majority of studies measuring retention of motor skills usually look at short-term retention, often corresponding to a delay of 24 hours before recall (Shea & Kohl, 1990; Shea et al., 2000). Thus, short-term retention is often confused with consolidation. Very few studies have directly examined long-term retention of a motor skill. In 1962, Fleishman and Parker looked at factors influencing retention and re-learning of a motor skill. Participants were trained on a complex hand tracking task over the course of 17 daily sessions. After a period of either 9, 14, or 24 months with no additional practice, participants were retested on the same task. Results showed that the groups were globally comparable at re-test, with no significant losses in performance. The longest delay group showed slight decreases in performance, however, the losses were minimal and were completely re-gained after 20 minutes of retraining. The authors concluded that "the most important factor in retention is the level of proficiency achieved by the participants during the initial learning. This effect is shown to be just as important following long and short periods with no practice" (p. 226). More recent studies have found similar behavioural results. For instance, on a visual discrimination task there was no forgetting even after three years without practice (Karni & Sagi, 1993). Furthermore, after a one month delay following five days of training on the TMST, there was almost no forgetting as evidence by no significant changes in percent correct, response variance, and response synchrony (Penhune & Doyon, 2002). However, in all of these studies, it was not clear whether retention was related to the amount of practice on the task or to the length of delay before recall. Therefore, a second aim of the current study was to examine the effects of amount of practice and length of delay on the retention of a motor task.

In summary, motor skill learning is an ongoing process that follows three stages: first, an early stage in which rapid improvements in performance occur within a single training session; second, a consolidation stage, following a period of rest of four to six hours or a night of sleep after the initial training session, in which improvements in performance continue to occur beyond training; and, third, a slower stage that occurs across several days or weeks, during which slow and gradual improvements in performance are still noted. After a certain amount of training, a motor skill becomes over-learned and no further gains in performance are observed. The skill can then be retained for long periods of time without practice. Neuroimaging studies have provided support for the stages of motor skill learning. Based on previous work, the goal of the present study is to examine the effects of different levels of practice and different lengths of delay on performance at different stages of learning and at delayed-recall of a motor skill. We used a motor sequence task that involves timing, in which participants were required to synchronize their finger press response with a visual stimulus. Given that timing was a parameter of interest, learning could not be assessed by reductions in mean reaction time, as is typically the case in most motor skill experiments. Thus, accuracy, variability of response, and response synchrony were evaluated to measure performance. We hypothesized that greater practice will lead to improved performance during learning and at delayed-recall. Furthermore, we expected that greater length of delay will lead to decreased performance at recall.

Method

Participants

The sample consisted of 58 healthy volunteers (30 males, 28 females). Participants were recruited by visits to various classes at Concordia University, flyers posted around the university campus, and by means of word of mouth. All participants were between the ages of 18 and 35 ($M = 23.97$, $SD = 4.30$), right handed, assessed using a handedness questionnaire adapted from Crovitz and Zener (1962), and selected to have less than three years of musical training or experience, assessed using a global Index of Musical Training and Experience (Penhune, 1999). None of the participants had a history of neurological disorders. Participants were requested to refrain from drinking alcohol prior to each testing session. Seven additional participants were tested, but were excluded from the final sample due to failure to learn the test within 48 trials, not presenting themselves on the final day of testing, or experimental error. The experimental protocol was approved by the Concordia University Human Research Ethics, Montreal, Canada. Participants gave informed consent and were compensated for their time.

Stimuli

The temporal motor sequence task (TMST) (Penhune & Doyon, 2002) used in this experiment requires participants to reproduce a complex timed motor sequence by tapping in synchrony with a visual stimulus using a single key of the computer mouse, with the index finger of the right hand. The stimuli were ten-element visual sequences, made-up of a series of white squares (3 cm^2) presented sequentially on a black background, in the center of the computer screen (21-inch Sony Trinitron Multiscan G500 computer monitor, running at 100 Hz).

Two sequences, designed to be of equal difficulty, were employed. Each participant was tested on only one of the two possible sequences, and the sequences were counterbalanced across participants. Each sequence was made-up of five long (750 ms) and five short (250 ms) elements, with a constant inter-stimulus interval (500 ms) (Figure 1). The sequences were constructed to have no more than two repeated elements and to have seven transitions from short to long. This results in sequences that are temporarily regular, but do not follow a typical musical rhythm (i.e. syncopated rhythms). The presentation of each sequence was cued by a smaller white square (1 cm^2) that appeared

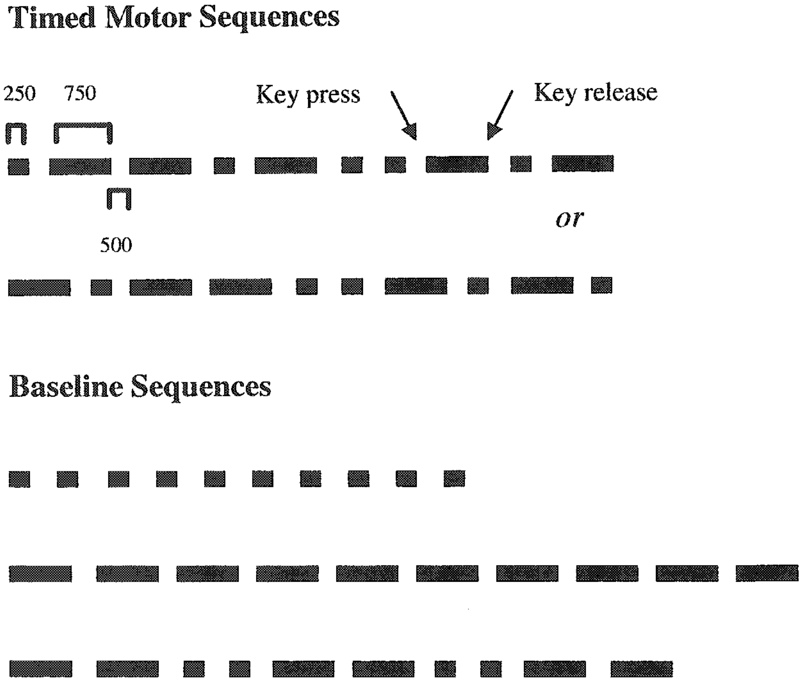

Figure 1. Depicts the temporal structure of the timed motor sequences and the baseline sequences (see stimuli). Sequences in both tasks comprised of white squares that appeared sequentially at the center of the computer monitor. Squares appeared for either long (750 ms) or short (250 ms) durations, with a constant inter-stimulus interval (500 ms). In this figure, long durations are represented by long dashes and short durations are represented by short dashes. For the timed motor sequence task, participants were only tested on one of the two sequences.

in the middle of the screen. Participants were instructed to press and hold the key down at the onset of each stimulus in the sequence, and to release it when the stimulus disappeared. Each block of practice on the TMST contained 12 presentations of the same sequence and lasted 2 min 12 s.

At each testing session, prior to performing the TMST, participants completed a baseline task that was used to score performance on the TMST. This task consisted of three simple ten-element sequences that were made-up of either all long, all short or simple-mixture (Figure 1). There were four repetitions of each sequence.

Custom software (Media Control Functions, Digivox, Montreal, Canada), running on an Intel Pentium III 800 MHz computer (under Windows Millennium), controlled stimulus delivery and automatically recorded participants' key-press and release durations, which were subsequently used to calculate the three indices of learning: accuracy of reproduction, variance of response duration, and percent asynchrony of responses with target stimuli.

Design and Procedure

Participants were randomly assigned to one of two conditions: a variable-practice condition ($n = 28$) or a variable-delay condition ($n = 40$) (Figure 2). Within each condition, participants were divided into groups (with 8 to 10 participants per group). Participants in the variable-practice condition were divided into 3 groups who received either 1 block (12 trials), 3 blocks (36 trials), or 6 blocks (72 trials) of practice on the TMST on each of five consecutive days, followed by a fixed 4-week delayed-recall. Participants in the variable-delay condition were divided into 4 groups who received 3 blocks of practice on the TMST on each of five consecutive days, followed by a variable

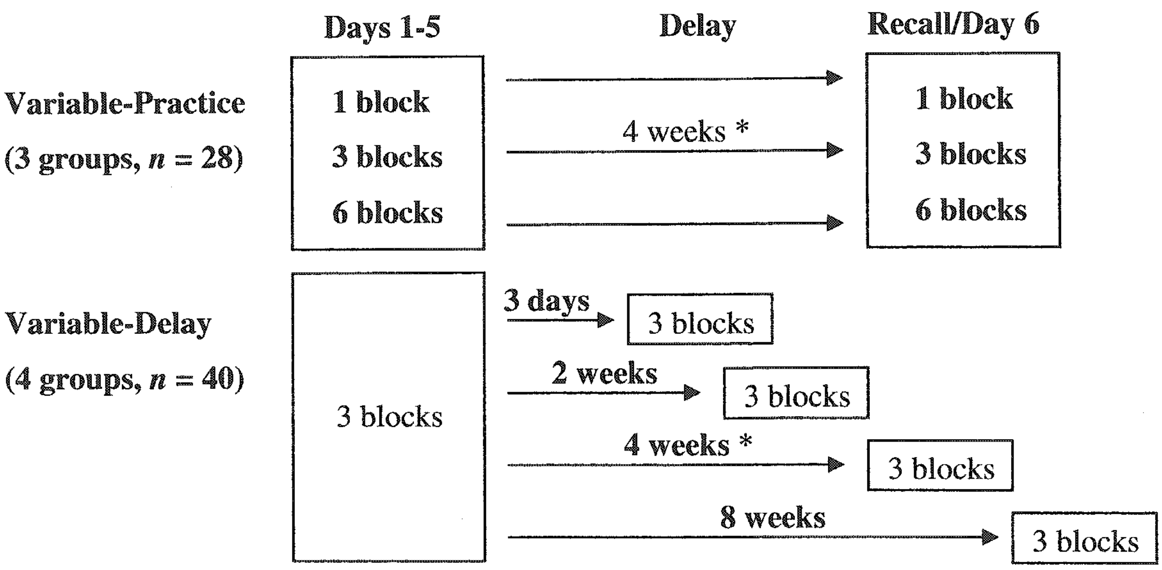

Figure 2. Illustrates the experimental design (see Design and Procedure). Participants were tested on five consecutive days (Days 1-5), followed by a delayed-recall session (Day 6), a few days or a few weeks later. Participants were randomly assigned to one of two conditions: a variable-practice condition or a variable-delay condition. Participants in the variable-practice condition received either 1, 3, or 6 blocks of practice on the TMST, followed by a fixed delayed-recall. Participants in the variable-delay group received a fixed amount of practice on the TMST, followed by a variable delayed-recall of either 3 days, or 2, 4, or 8 weeks. The group who received 3 blocks of practice followed by a 4-week delayed-recall was included in both conditions.

delayed-recall of either 3 days, or 2, 4, or 8 weeks. The group who received 3 blocks of practice followed by a 4-week delayed-recall was included in the analyses for both conditions.

Testing occurred on 5 consecutive sessions (Days 1-5), followed by a delayed-recall session (Day 6). On all testing days, participants first completed the baseline task used to score the TMST. On Day 1, participants were trained to reproduce one of the two timed motor sequences, to a criterion of three consecutive correct repetitions. After this initial training, participants were no longer provided feedback on their performance. On Days 1-5, participants completed 1-6 blocks of practice on the TMST. On each day, participants briefly reviewed the timed motor sequence by reproducing it one to two times prior to beginning practice. After a delay with no practice, participants returned to the laboratory for a final testing session (Day 6), and followed the same protocol as per Days 2-5.

Participants were always seated 57 cm away from the computer monitor. Breaks were provided between blocks of practice to prevent fatigue and optimize performance. Participants were specifically instructed not to practice the sequences between sessions and were debriefed on the final day of testing to ensure they complied with that instruction.

Measures

Since timing was a parameter of interest in this study, as participants explicitly learned to synchronize their response with the target stimuli, learning was not measured by decreases in reaction time, as is the case in classic motor skill learning experiments. Instead, learning was assessed by investigating changes in three variables: accuracy, response variance, and percent response asynchrony. Accuracy was scored individually, by using each participant's average short and long responses from the baseline sequences, for each day, ± 2 SD as the upper and lower limits for correct response for short and long elements, respectively. Percentage of correct values was calculated for each presentation of the timed motor sequence. Response variance measured the stability of response, by using the coefficient of variation (SD/M) of correct responses durations. Finally, percent response asynchrony measured the percent difference between onset and offset of stimuli and onset and offset of response (for additional information on scoring of the sequence, refer to Penhune, Zatorre, & Feindel, 1999).

Statistical Analysis

All dependent measures were averaged across blocks and days of practice, for each of the two conditions. The data were analyzed with repeated measure ANOVAs (Greenhouse-Geiser correction), with Group as the between-subjects factor and Day or Block as within-subject factors. Differences across Days 1-5 of learning, across the last block of practice on Day 1 and the first block of practice on Day 2 (LBD1-FBD2; consolidation), and across the last block of practice on Day 5 and the first block of practice on Day 6 (LBD5-FBD6; delayed-recall) were evaluated for the two conditions separately. In addition, one-way ANOVAs, with group as the between-subjects factor, were conducted to assess performance across blocks of practice on Day 1 (early learning) for the two conditions, and across blocks of practice on Day 6 (re-learning) only for the varied-delay condition. Significant main effects and interactions were analyzed using pairwise comparisons, with Bonferroni adjustment for multiple comparisons. The α level was set at .05 for all statistical tests.

Results

Varied-Practice Condition

A one-way analysis of variance indicated that mean age did not differ between the three groups, F(2, 24) = .25, p = .78. Groups did not differ on trials to criterion for explicit learning of the TMST on Day 1, F(2, 23) = .93, p = .41, indicating no pre-training differences in learning capacity. Furthermore, there were no significant differences between the sexes, F(1, 24) = 2.90, p = .10, nor between the two timed motor sequences, F (1, 24) = .20, p = .66, on trials to criterion. Therefore data were collapsed across these two dimensions.

Days 1-5 of learning. Contrary to our hypothesis, groups did not differ in their performance as measured by percent correct, response variance, or percent response asynchrony when compared across Days 1-5 of learning (Figure 3). These results indicate that amount of practice did not affect learning of the TMST. However, collapsed across groups, significant changes were observed for all three measures across days of learning, percent correct: F(2.33, 4.65) = 22.63, p = .00, coefficient of variation: F(1.91, 3.83) = 27.75, p = .00, percent response asynchrony: F(2.59, 5.18) = 52.37, p = .00. Post hoc comparisons showed a similar pattern of results for all measures, with overall significant improvements in performance between Days 1-4 ($p < .05$), but not between Days 4-5, suggesting that participants appeared to be reaching a plateau in performance by Day 4.

Learning Day 1. Surprisingly, no significant differences were observed for any dependent variable when comparing the final block of practice for each group on Day 1, suggesting that amount of practice, per se, had no effect on early learning of the TMST.

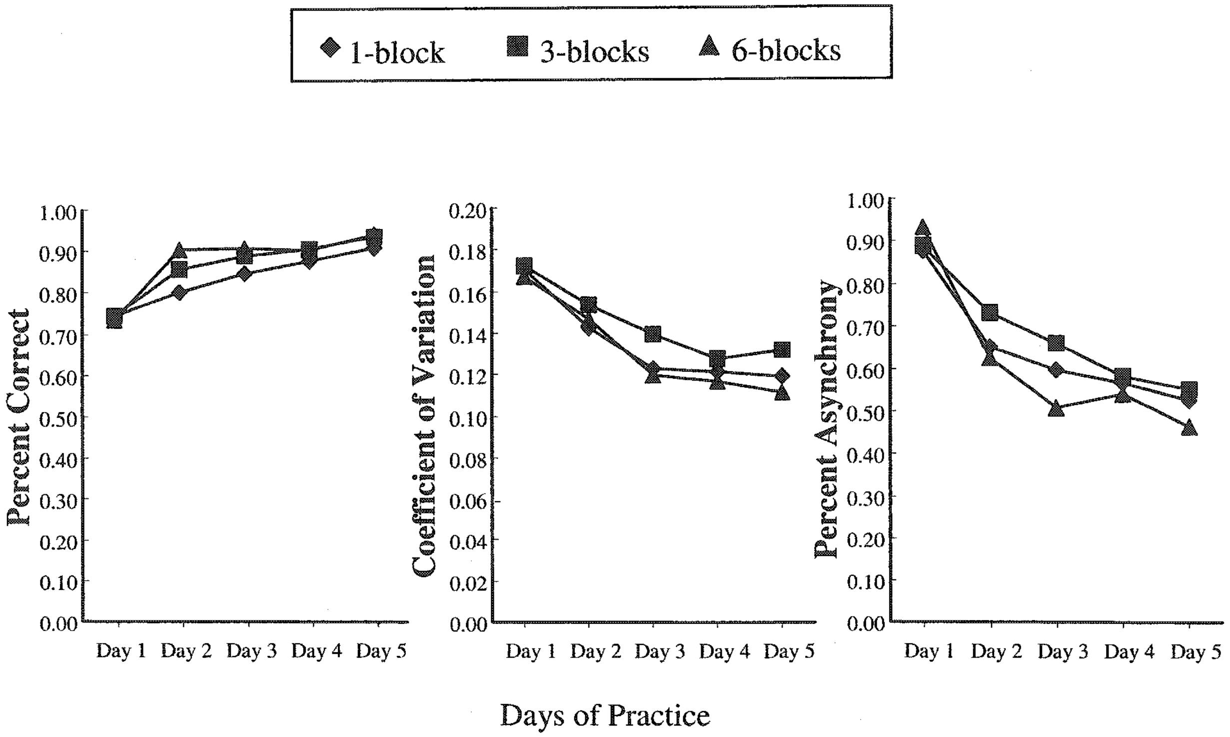

Figure 3. Illustrates a significant improvement in performance for the variable practice groups across days of practice for all dependent measures. The left graph shows the change in percent correct values; the middle graph shows changes in response variance; and the right graph shows changes in percent response asynchrony.

Consolidation. For both percent correct and percent asynchrony values, significant improvements were observed between the last block of practice on Day 1 and the first block of practice on Day 2, percent correct: F(1, 2) = 5.72, $p = .025$, percent response asynchrony: F(1, 2) = 13.93, $p = .00$, indicating that learning of the TMST continued following a night of sleep without additional practice (Figure 4). For response variance, a Group X Day interaction approached significance, F(2, 24) = 3.04, $p = .07$, (Figure 4) with post hoc comparisons revealing marginally significant improvements in performance for the 1-block practice group ($p = .07$) and the 3-block practice group ($p = .06$), but not for the 6-block practice group ($p = .26$).

Recall. Comparisons of percent correct and response variance for the last block of practice on Day 5 and the first block of practice on Day 6 showed no significant changes for any group, indicating that overall, the sequences were well retained (Figure 5). For percent response asynchrony, there was a significant Day X Group interaction, F(2, 24) = 5.118, $p = .01$ (Figure 5). Post hoc analyses revealed that the only group that showed significant decrements in performance was the 3-block practice group ($p=.01$).

Varied-Delay Condition

A one-way analysis of variance showed that average mean age did not differ between the four groups, F(3, 36) = 1.24, $p = .31$. Groups did not differ on trials to criterion for explicit learning of the TMST on Day 1, F(3, 36) = 1.27, $p = .30$, indicating no pre-training differences in learning capacity. Furthermore, there were no significant differences between the sexes, F(1, 38) = 1.91, $p = .18$, nor between the two timed motor sequences, F(1, 38) = .034, $p = .86$, on trials to criterion. Therefore data were collapsed across these two dimensions.

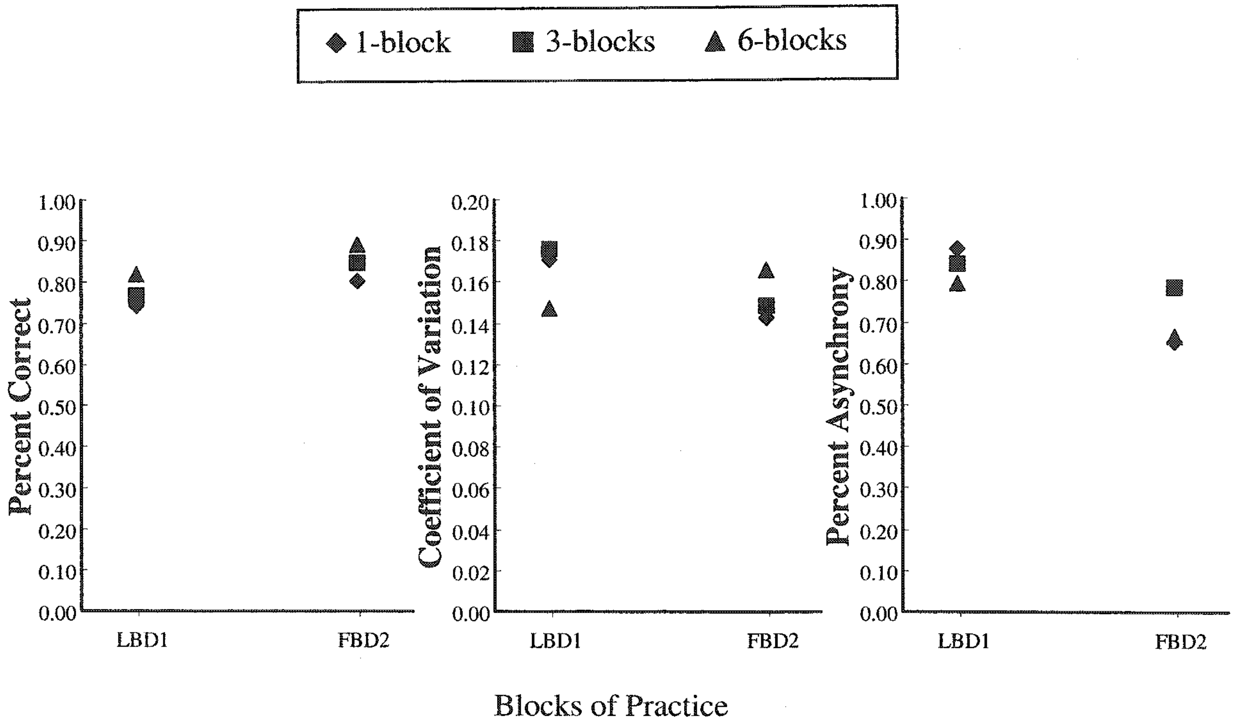

Figure 4. Illustrates significant improvement in performance for the variable practice groups between the last block of practice on Day 1 (LBD1) and the first block of practice on Day 2 (FBD2) for percent correct (left graph) and percent response asynchrony (right graph). There was also a Group X Day interaction that approached significance for response variance (middle graph), such that the 1-block practice group and the 3-block practice group showed marginally significant improvement between LBD1-FBD2.

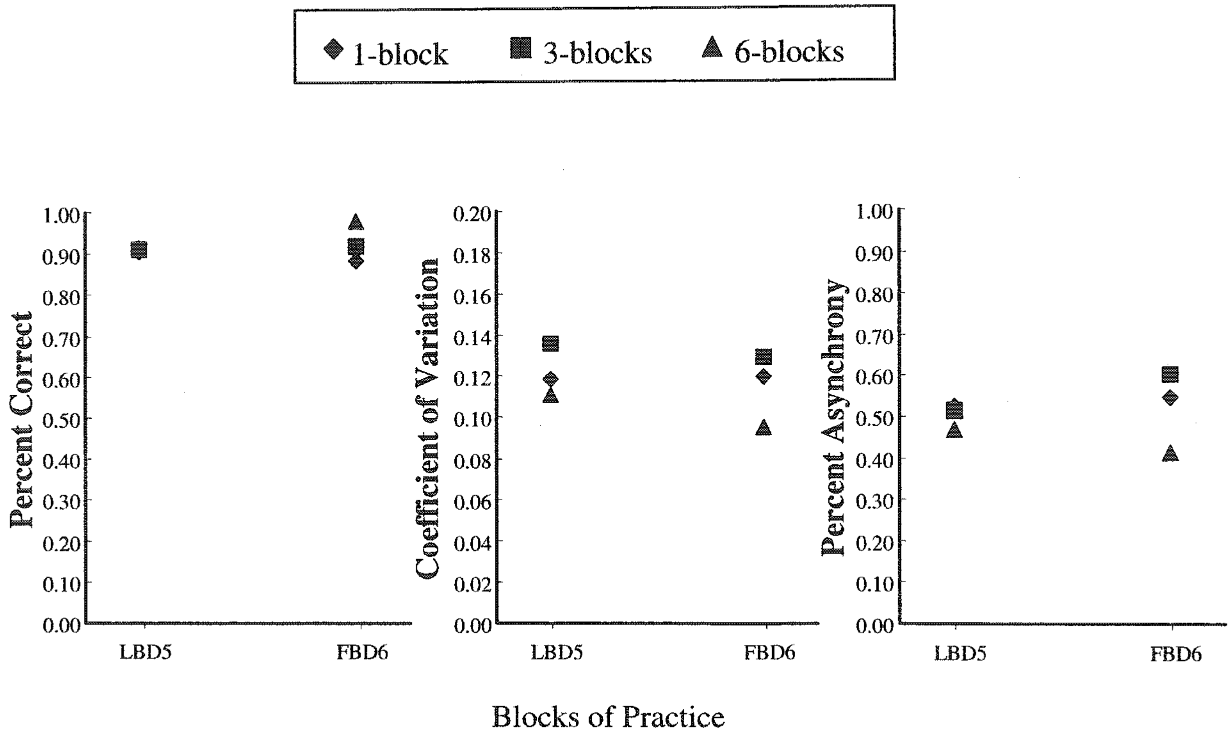

Figure 5. Illustrates no significant changes in performance for the variable practice groups between the last block of practice on Day 5 (LBD5) and the first block of practice on Day 6 (FBD6) for percent correct (left graph) and response variance (middle graph). However, there was a significant Group X Day interaction for percent response asynchrony, such that only the 3-block practice group showed significant decrements in performance between LBD5-FBD6 (right graph).

One participant from the 3-block practice group was excluded from the analyses when comparing performance across blocks of practice at delayed-recall (experimental error).

Days 1-5 of learning. The groups did not differ in their performance as measured by percent correct, response variance, or percent asynchrony, when compared across Days 1-5 of learning, indicating no differences in level of learning before recall (Figure 6). Across days of practice, all groups showed significant improvements in performance for all three measures, percent correct: F(2.32, 6.95) = 29.22, $p = .00$, coefficient of variation: F(2.34, 7.02) = 39.97, $p = .00$, percent response asynchrony: F(1.67, 5) = 58.05, $p = .00$. Post hoc analyses showed a similar pattern of results for all measures, with overall significant improvements in performance between Days 1-4 ($p < .05$), but not between Days 4-5, indicating that participants appeared to be reaching a plateau in performance by Day 4.

Learning Day 1. As expected, no significant group differences were observed across blocks of practice on Day 1 for any dependent variable. All groups showed significant improvement in performance across blocks as measured by percent correct, F(1.91, 5.72) = 4.58, $p = .015$, and percent asynchrony, F(1.64, 4.91) = 15.53, $p = .00$, but not response variance. For percent correct and percent response asynchrony, post hoc analyses yielded significant differences between the first and last block of practice ($p < .05$).

Consolidation. There were no significant group differences between the last block of practice on Day 1 and the first block of practice on Day 2 (Figure 7). All groups showed significant improvements in performance for all three measures ($p < .05$), indicating that learning of the TMST continued following a night of sleep without additional practice.

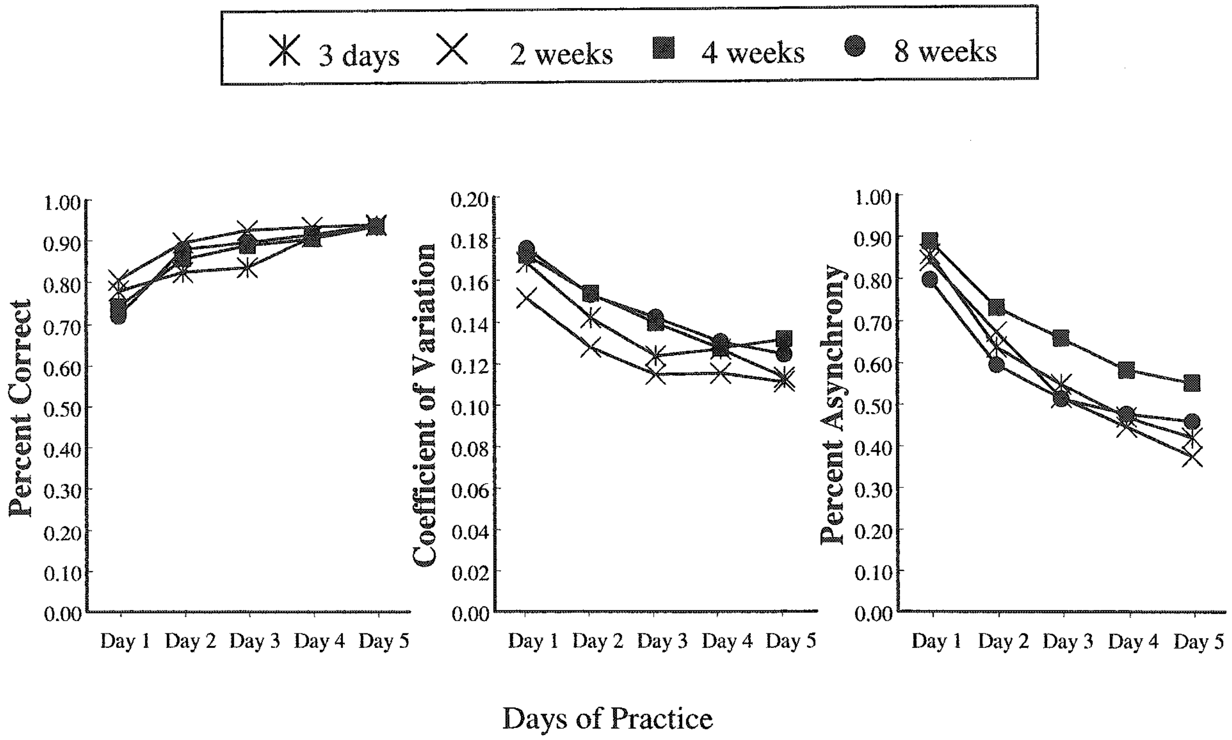

Figure 6. Illustrates a significant improvement in performance for the variable delay groups across days of practice for all dependent measures. The left graph shows the change in percent correct values; the middle graph shows changes in response variance; and the right graph shows changes in percent response asynchrony.

Recall. For percent correct, there was a marginally significant Day X Group interaction, F(3, 36) = 2.48, $p = .08$, such that only the 8-week delay group showed significant decrements in performance between the last block of practice on Day 5 and the first block of practice on Day 6 ($p = .04$) (Figure 8). These results indicate that longer lengths of delay before recall appear to negatively affect explicit components of the TMST. Contrary to our hypothesis, comparisons of response variance and percent response asynchrony revealed no significant group differences (Figure 8). However, there were significant decrements in performance at delayed-recall for percent response asynchrony for all groups, F(1, 3) = 5.31, $p = .03$, suggesting that this measure is sensitive to delay, but not length of delay per se. Interestingly, there were significant improvements in performance in percent response asynchrony across blocks of practice on Day 6, for all groups, F(1.76, 5.29) = 5.74, $p = .01$. Post hoc analyses revealed that the first and second block of practice significantly differed from the last block of practice ($p < .05$) indicating that all groups appeared to be re-learning how to synchronize with the stimulus (Figure 8).

Discussion

The present study examines the effects of different levels of practice and different lengths of delay on the learning and retention of the TMST. For the varied-practice condition, our results demonstrated that all groups showed a similar level and rate of learning across the five days of practice, indicating that amount of practice did not affect acquisition of the TMST. We therefore concluded that distribution of practice, rather than amount of practice, may be the most important factor affecting learning. Furthermore, no significant group differences were found between day 5 and recall,

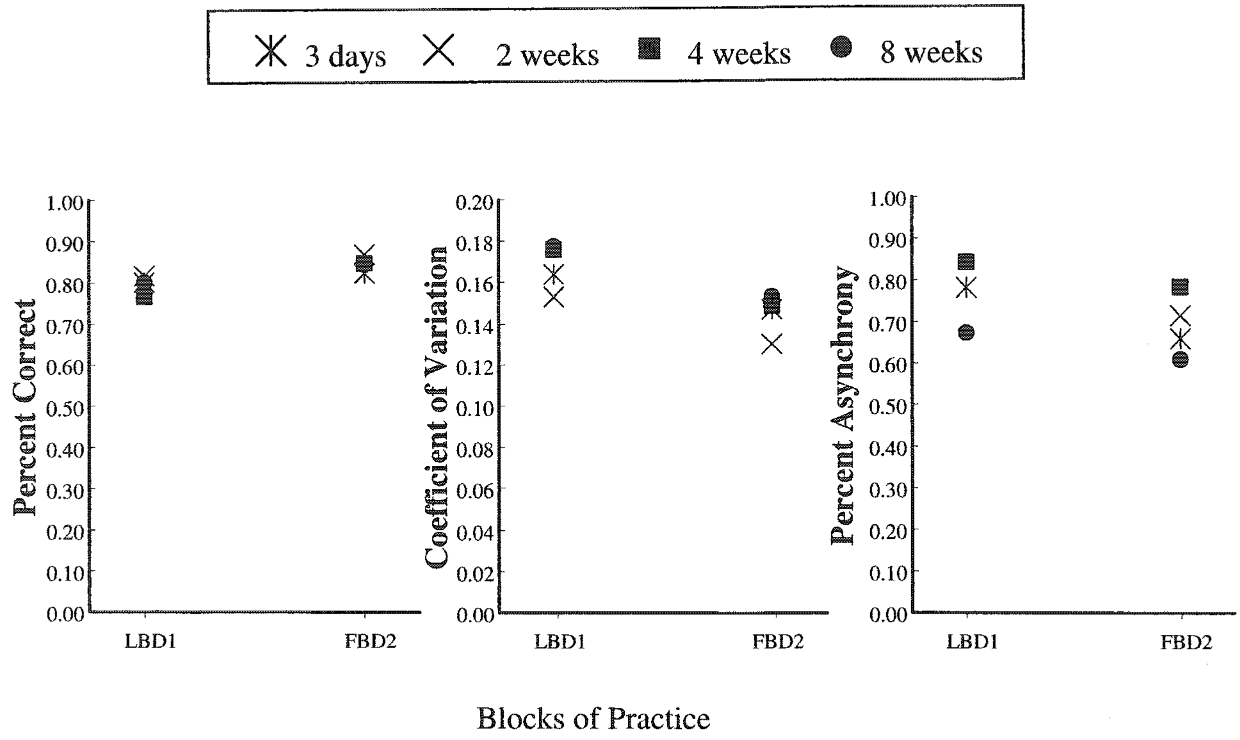

Figure 7. Illustrates significant improvement in performance for the variable delay groups between the last block of practice on Day 1 (LBD1) and the first block of practice on Day 2 (FBD2) for percent correct (left graph), response variance (middle graph), and percent response asynchrony (right graph).

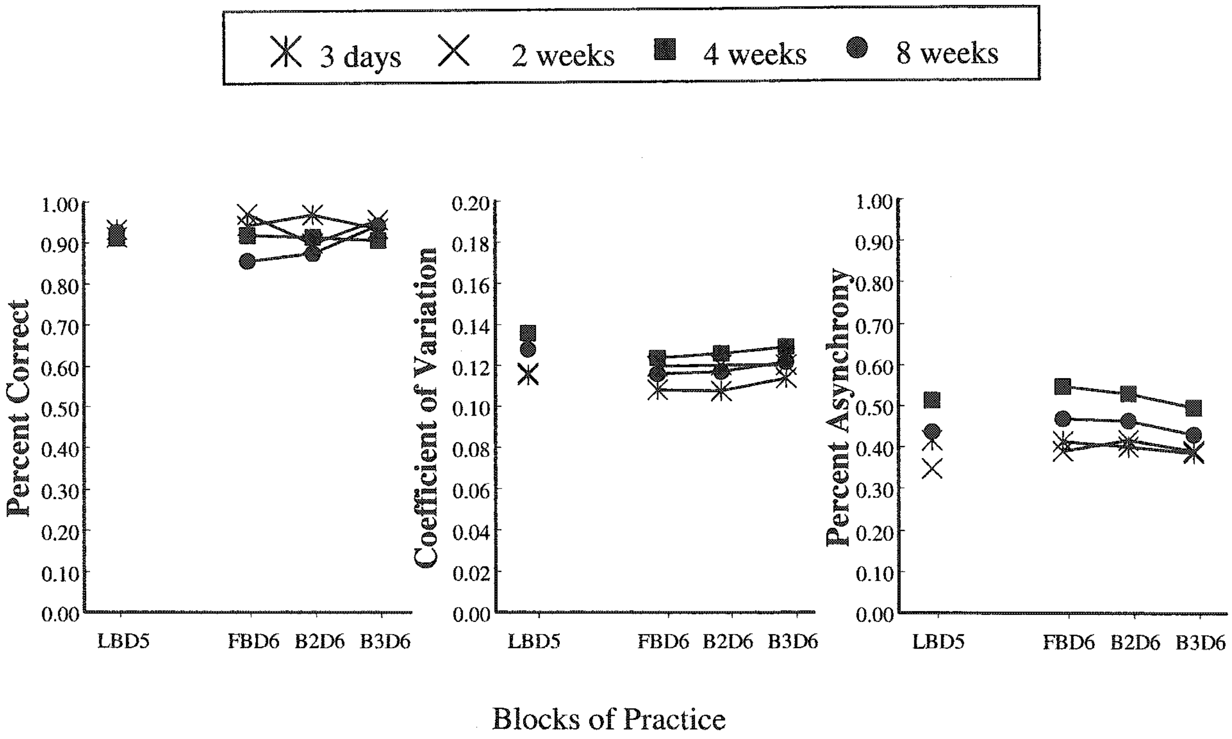

Figure 8. Illustrates no significant changes in performance for the variable delay groups between the last block of practice on Day 5 (LBD5) and the first block of practice on Day 6 (FBD6) for response variance (middle graph) and percent response asynchrony (right graph). However, there was a marginally significant Group X Day interaction for percent correct, such that only the 8-week delay group showed significant decrements in performance between LBD5-FBD6 (right graph). Furthermore, there were significant improvements in performance only for percent response asynchrony across blocks of practice on Day 6, for all groups (right graph).

suggesting that the amount of practice did not affect retention. One explanation may be that final level of performance, rather than amount of practice, may be the principal variable that determines retention of a motor skill. In the varied-delay condition, delay differentially affected specific parameters of performance at recall. First, only the longest delay group showed decrements in percent correct between day 5 and recall, suggesting that longer lengths of delay might hinder retrieval of explicit aspects of the temporal motor sequence. Second, all groups showed a decrement in percent response asynchrony between day 5 and recall. This finding indicates that percent response asynchrony is sensitive to delay, although not to the length of delay.

Effects of Practice on Motor Skill Learning

The first goal of this study was to examine the effects of practice on motor skill learning. Contrary to our hypothesis that greater practice would lead to improved performance on the TMST, no significant group differences were observed for the varied-practice condition across days 1 to 5 of practice, across blocks of practice on day 1, or between the last block of practice on day 1 and the first block of practice on day 2 (i.e. consolidation). These findings are surprising given that the group that received only 1 block of practice performed as well as the groups who received either 3 or 6 blocks of practice, indicating that amount of practice did not influence learning. It may be argued that the reason why no group differences were found is that all participants were explicitly taught the TMST prior to practicing it, leaving little room for improvement. However, participants did not start at ceiling as average performance on day 1 for percent correct for all groups was only $M = .74$ ($SD = .15$), with very similar averages for all three groups (1-block: $M = .74$, $SD = .15$; 3-blocks: $M = .74$, $SD = .13$; 6-blocks: $M = .73$, *SD* = .19). Furthermore, participants continued to show improvements in performance across the subsequent days of practice. In fact, analyses for all three measures revealed improvements in performance across days 1 to 4 of practice, but not between days 4 to 5, suggesting that it was only at day 4 that task performance had stabilized. A similar pattern of findings was observed for the varied-delay groups who received a fixed amount of practice.

The fact that we did not find any performance differences between the varied practice groups but found global improvements across days of practice, indicates that total amount of practice is not the major factor affecting learning. Rather, distribution of practice across several days may be a more important variable that influences performance and learning. This hypothesis is consistent with previous studies that have shown that spaced practice augments subsequent performance on motor tasks, relative to massed or continuous practice (Baddely & Longman, 1978; Shea et al., 2000). For example, Baddeley and Longman (1978) found that learning a typing task was enhanced when training was provided one hour a day for 60 days as opposed to two sessions of two hours a day for 15 days. Thus, spacing practice over several sessions might contribute to enhanced learning because it allows for more time to process and encode the information received (see Dempster, 1996, for review).

Related to the notion of spaced practice, studies of consolidation have consistently shown that a period of rest or a night of sleep significantly enhances learning on a recently acquired motor skill (Karni, Tanne, Rubenstein, & Askenasy, 1994; Mullbacher et al., 2002; Shea et al., 2000; Walker et al., 2002). For instance, Walker et al. (2002) reported that after a 12-hour night of sleep, compared to a 12-hour wake period, significant gains in speed and accuracy were found for a sequential finger tapping task. This is in agreement with our finding that learning continued to take place after an initial practice session in both the varied-practice and varied-delay conditions, when comparing the last block of practice on day 1 to the first block of practice on day 2. Neuroimaging data demonstrate that sleep is particularly important for increasing the functional activity in neural regions that are critical for learning new motor sequences, such as the cerebellum (Maquet et al., 2003). Rest is thus essential for a maximum benefit of practice to be gained, as the time delay may allow for higher level integration of learning, possibly reflecting changes in cognitive and neuronal representations of the skill. Perhaps then behavioural and neural mechanisms show greatest effects between day 1 and day 2, indicating that consolidation is an ongoing process, across days of practice, which may lead to plateau in performance.

Our results showed that amount of practice did not affect the rate of learning on the TMST, as the group with the least amount of practice and the group with the most amount of practice reached a plateau in performance at the same time (i.e. by day 4 of practice). There has been a lack of studies that have directly examined ceiling effects on the acquisition of motor skills. As a consequence, there is no clear operational definition of what constitutes asymptotic performance. Karni et al. (1998) reported that participants approached asymptotic performance by approximately the third week of practice on a finger-to-thumb opposition task. Although asymptotic performance was not clearly defined, their findings translated into an enlarged representation of the trained sequence, as oppose to an untrained sequence, in the primary motor cortex. The authors speculated that training, over a relatively long period of time, may have a direct effect on the reorganization of the motor cortex. In the present study, plateau in performance was defined as an absence of change in performance based on repeated measure ANOVAs between days of practice. For both the varied-practice and varied-delay conditions, performance on all three measures of learning approached ceiling by day 4, as evidenced by no significant improvements between days 4-5. It could be hypothesized that ceiling effects observed reflected permanent changes in neural systems that are involved in the storage of motor programs. Thus, future behavioural and neuroimaging studies should further consider the nature of asymptotic performance.

An important issue to consider when examining rate at which performance improves, is whether the experimental paradigm required an implicit form of learning or an explicit form of learning. In an implicit paradigm, participants follow two phases of learning: one related to acquiring the movements, and the other related to optimizing performance. In an explicit paradigm, participants receive pre-training on the sequence prior to practice; learning thus involves only one phase, namely optimization of the movements. In the present experiment, the task involved both explicit and implicit forms of learning. One might expect that ceiling effects are reached more rapidly in a purely explicit paradigm as learning mainly entails fine-tuning of the movements. An analogy can be drawn with practice related to experience. A novice musician has to first learn the cognitive abilities related to the musical piece, such as learning to read the notes. After significant practice however, the musician concentrates more on motor abilities. An expert performer, on the other hand, primarily focuses on motor abilities as cognitive abilities have already become automatic (Schmidt, 1991).

Taken together, our results showed that level and rate of performance both changed across days of practice. Amount of practice, however, had no effect on motor skill learning. These results indicate that spreading sessions of practice over several days, even with minimal practice on every day, might have a greater effect on learning.

Effects of Practice on Motor Skill Retention

The second aim of this experiment was to look at the effects of practice on motor skill retention. Contrary to our hypothesis that greater practice would lead to enhanced retention of the TMST, the analyses showed that all three groups in the varied-practice condition performed equally well at delayed-recall with no significant losses in performance. Therefore, once learned, the TMST is relatively well retained even after one month without practice. Other studies have found similarly good retention for periods up to two or three years. However, in these studies the amount of practice was fixed (Hikosaka et al., 2002; Karni et al., 1998; Nezafat, Shadmehr, & Holocomb, 2001). Findings from our study suggest that amount of practice, per se, is not the primary factor influencing retention, since the 1-block practice group showed similar performance as the 3-block and 6-block practice groups at recall. Based on our results, we postulate that what may be critical for retention is the degree of proficiency attained during original learning of the skill, as there is almost no forgetting after performance has reached plateau (Karni, 1996; Nezafat, Shadmehr, & Holocomb, 2001). For instance, Fleishman & Parker (1962) correlated final performance level on an arm-movement tracking task at the end of 17 sessions of practice distributed over a period of 6 weeks, and at retention following a delay of 1, 5, 9 or 14 months. Results demonstrated that level of proficiency achieved by all participants, as measured by the average score for the final three training days was highly related to performance at retention. The correlations were similar for the shorter and longer delay groups, suggesting that there are strong effects of initial learning on both short- and long-term retention.

Effects of Delay on Motor Skill Retention

The final goal of the present investigation was to look at the effects of length of delay on motor skill retention. In the varied-delay condition, only the 8-week delay group showed significant decrements in percent correct, and all groups showed decrements in percent asynchrony at recall. This pattern of findings indicates that it is likely that motor skills are stored and retained in different ways. In line with this conclusion, Hikosaka, Rand, Nakamura, Miyachi, Kitaguchi, Sakai, Lu, & Shimo (2002) recently proposed that motor skills are acquired and retained in two independent but parallel forms, speed and accuracy. In this study, both humans and monkeys were trained on a visuo-motor sequence task. Participants practiced the sequences for about a week and a half (animals practiced the sequences for longer periods of time). After a delay of 16 months, participants returned for two additional testing sessions. On day 1, participants learned new sequences. On day 2, participants performed the old sequences and the recently acquired sequences (learned the prior day). Interestingly, accuracy was higher for the recently acquired sequences compared to the old sequences, but speed of performance was higher for the old sequences than the recent sequences. Comparable findings were found for the animal subjects. The authors concluded that speed of performance, rather than accuracy, is retained for more extended periods of time. This conclusion suggests that the motor component (i.e. speed) of the task is better remembered than the explicit component (i.e. accuracy) of the task. These results support our finding that the longest delay group showed significant losses in response accuracy at recall. We found that length of delay affected the recall of the order of elements in a temporal motor sequence; delay, but not length of delay, hindered retention of synchronization; and, neither delay nor length of delay affected stabilization of response variance. This indicates that the explicit component of the task (i.e. accuracy) was the most sensitive to the length of delay before recall, but only a long delay hindered performance. On the other hand, motor components of the task (i.e. synchronization) required ongoing practice in order to be maintained. Perhaps, the reason for these differences is that different aspects of a motor skill are encoded in different neural systems that work independently, and delay might impede retrieval of some, but not all of these aspects. The question still remains what makes certain systems more robust to delay than others?

Overall, delay differentially influenced motor skill retention. First, length of delay affected response accuracy at recall. Second, delay, but not length of delay, influenced ability of participants to synchronize with the target stimulus. Finally, neither length of delay nor delay had any effect on response variance. Therefore, it is likely that different aspects of motor skills are stored in various independent but parallel systems.

Important Considerations and Future Directions

In the current study, participants acquired and retained a relatively simple motor sequence task under very stable and constrained conditions. An important point to bear in mind is that in many real-world situations the ultimate goals of practice are generalization and transfer of skills acquired (Schmidt, 1991). Future research should explore the effects of practice and delay on the generalization and transfer of the TMST.

Another important consideration relates to possible individual differences in performance. We examined group differences in scores on each of the three variables averaged across participants. This method does not allow us to look at possible individual differences in the pattern of learning and retention. Since we found that level of proficiency may be a key factor that affects learning and retention, an interesting aspect of the data that could be explored with other types of analyses is individual differences in patterns of performance related to practice or delay. Possibly, rate of learning and degree of retention at delayed-recall may be predicted based on performance on the initial day of learning. In addition, similar questions could be addressed in a neuroimaging paradigm that looks at the effects of performance proficiency on different cortical and subcortical structures during early and late learning and at retention.

To our knowledge, the present investigation is the first to examine the effects of both practice and delay on the learning and retention of a temporal motor sequence task. Surprisingly, results showed that amount of practice had no significant effect on the learning and retention of the TMST, suggesting that even minimal amounts of practice spread over several days are sufficient to induce long-term memory of a motor skill. Furthermore, delay appeared to differentially affect retention of the TMST, as length of delay influenced response accuracy, delay affected response synchronization, and neither delay nor length of delay had effects on response variance. These results indicate that different aspects of a motor skill are stored in independent but parallel systems. We propose that level of proficiency, rather than amount of practice or length of delay is the critical factor affecting motor skill learning and retention. Future studies aimed at elucidating the neural basis of motor skill learning and retention as related to performance proficiency will shed light on this question.

References

Bourne, L. E., Jr., & Archer, E. J. (1956). Time continuously on target as a function of distribution of practice. *Journal of Experimental Psychology, 51*, 25-33.

Crovitz, H. F., & Zener, K. (1962). A group-test for asessing hand- and eye-dominance. *American Journal of Psychology, 75*(2), 271-276.

Dempster, F. N. (1996). Distributing and managing the conditions of encoding and practice. In E. L. Bjork & R. A. Bjork (Eds.), *Memory: Handbook of perception and cognition (2nd ed.)* (pp. 317-344). New York: Academic Press.

Doyon, J., Owen, A. M., Petrides, M., Sziklas, V., & Evans, A. C. (1996). Functional anatomy of visuomotor skill learning in human subjects examined with positron emission tomography. *European Journal of Neuroscience, 8*(4), 637-648.

Doyon, J., & Ungerleider, L. G. (2002). Functional anatomy of motor skill learning. In L. R. Squire (Ed.), (pp. 225-238). New York, NY, US: Guilford Press.

Fleishman, E. A., & Parker, J. F., Jr. (1962). Factors in the retention and relearning of perceptual-motor skill. *Journal of Experimental Psychology, 64*(3), 215 226.

Grafton, S. T., Woods, R. P., & Tyszka, M. (1993). Functional imaging of procedural motor learning: Relating cerebral blood flow with individual subject performance. *Human Brain Mapping, 1*(3), 221-234.

Healy, A. F., & Sinclair, G. P. (1996). The long-term retention of training and instruction. In E. L. Bjork & R. A. Bjork (Eds.), *Memory. Handbook of perception and cognition (2nd ed.)* (pp. 525-564). New York: Academic Press.

Hikosaka, O., Nakahara, H., Rand, M. K., Sakai, K., Lu, X., Nakamura, K., Miyachi, S., & Doya, K. (1999). Parallel neural networks for learning sequential procedures.

Trends in Neurosciences, 22(10), 464-471.

Hikosaka, O., Nakamura, K., Sakai, K., & Nakahara, H. (2002). Central mechanisms of motor skill learning. *Current Opinion in Neurobiology, 12*(2), 217-222.

Hikosaka, O., Rand, M. K., Nakamura, K., Miyachi, S., Kitaguchi, K., Sakai, K., Lu, X., & Shimo, Y. (2002). Long-term retention of motor skill in macaque monkeys and humans. *Experimental Brain Research, 147*(4), 494-504.

Karni, A. (1996). The acquisition of perceptual and motor skills: A memory system in the adult human cortex. *Cognitive Brain Research, 5*(1-2), 39-48.

Karni, A., Meyer, G., Jezzard, P., & Adams, M. M. (1995). Functional MRI evidence for adult motor cortex plasticity during motor skill learning. *Nature, 377*(6545), 155-158.

Karni, A., Meyer, G., Rey-Hipolito, C., Jezzard, P., Adams, M. M., Turner, R., & Ungerleider, L. G. (1998). The acquisition of skilled motor performance: fast and slow experience-driven changes in primary motor cortex. *Proceedings of the National Academy of Sciences of the United States of America, 95*(3), 861-868.

Karni, A., & Sagi, D. (1993). The time course of learning a visual skill. *Nature, 365*(6443), 250-252.

Karni, A., Tanne, D., Rubenstein, B. S., & Askenasy, J. M. (1994). Dependence on REM sleep of overnight improvement of a perceptual skill. *Science, 265*(5172), 679-682.

Maquet, P., Schwartz, S., Passingham, R., & Frith, C. (2003). Sleep-related consolidation of a visuomotor skill: Brain mechanisms as assessed by functional magnetic resonance imaging. *Journal of Neuroscience, 23*(4), 1432-1440.

Muellbacher, W., Ziemann, U., Wissel, J., Dang, N., Kofler, M., Facchini, S., Boroojerdi, B., Poewe, W., & Hallett, M. (2002). Early consolidation in human primary motor cortex. *Nature, 415*(6872), 640-643.

Penhune, V. B., & Doyon, J. (2002). Dynamic cortical and subcortical networks in learning and delayed recall of timed motor sequences. *Journal of Neuroscience, 22*(4), 1397-1406.

Penhune, V. B., Zatorre, R. J., & Feindel, W. H. (1999). The role of auditory cortex in retention of rhythmic patterns as studied in patients with temporal lobe removals including Heschl's gyrus. *Neuropsychologia, 37*(3), 315-331.

Schmidt, R. A. (1991). *Motor learning & performance: From principles to practice.* Champaign, IL, US: Human Kinetics Books.

Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: A behavioral emphasis* (3rd ed.). Champaign, IL, US: Human Kinetics.

Shadmehr, R., & Brashers Krug, T. (1997). Functional stages in the formation of human long-term motor memory. *Journal of Neuroscience, 17*(1), 409-419.

Shea, C. H., & Kohl, R. M. (1990). Specificity and variability of practice. *Research Quarterly, 61*(2), 169-177.

Shea, C. H., Lai, Q., Black, C., & Park, J. H. (2000). Spacing practice sessions across days benefits the learning of motor skills. *Human Movement Science, 19*(5), 737-760.

Stickgold, R., Hobson, J. A., Fosse, R., & Fosse, M. (2001). Sleep, learning, and dreams: Off-line memory reprocessing. *Science, 294*(5544), 1052-1057.

Toni, I., Krams, M., Turner, R., & Passingham, R. E. (1998). The time course of changes during motor sequence learning: a whole-brain fMRI study. *Neuroimage, 8*(1), 50-61.

Van Mier, H. V. (2000). Human learning. In A. W. Toga & J. C. Mazziotta (Eds.), *Brain mapping: The systems* (pp. 605 620).

Walker, M. P., Brakefield, T., Morgan, A., Hobson, J. A., & Stickgold, R. (2002). Practice with sleep makes perfect: sleep-dependent motor skill learning. *Neuron, 35*(1), 205-211.

Welford, A. T. (1987). On rates of improvement with practice. *Journal of Motor Behavior, 19*(3), 401-415.

Willingham, D. B. (1998). A neuropsychological theory of motor skill learning. *Psychological Review, 105*(3), 558-584.

Appendix A

Consent Form

LABORATORY FOR MOTOR LEARNING AND NEURAL PLASTICITY
CONSENT FORM TO PARTICIPATE IN RESEARCH

Title of project: The Effects of Practice and Delay on Motor Skill Learning and Retention
Researchers: Dr. Virginia Penhune
Tal Savion-Lemieux

This is to state that I agree to participate in a program of research being conducted in the Laboratory for Motor Skill Learning and Neural Plasticity in the Department of Psychology at Concordia University.

A. PURPOSE

The purpose of this study is to advance our knowledge of how the brain learns precise motor skills, similar to playing the piano. In the future, this knowledge may also increase our understanding of brain disorders resulting from disease or injury.

B. PROCEDURES

This experiment includes 6 testing sessions. The first session lasts approximately 30 minutes. In this session, you will be taught to make a sequence of finger taps in time with a visual stimulus presented on the computer. You will be asked to reproduce the sequence by tapping in synchrony with the visual stimulus using a single mouse key. You will then be asked to practice this sequence for approximately 15 minutes. On the following 5 days, you will be asked to return to the lab and practice the same sequence for approximately 15 minutes. It is very important that you refrain from practicing the sequence between sessions. It is also very important that you refrain from drinking alcohol 24 hours prior to each testing session. You will be compensated $30 for your time and willingness to contribute to this research study.

Advantages and disadvantages: Participation in this study has no personal benefits. On a long term basis, the study may help us gain knowledge about brain functioning. There are no physical risks associated with participation in this experiment. The only disadvantage of participation is the time you will spend doing the test and traveling to and from the laboratory. The investigator may end the study at any time for purely scientific reasons. In this case, compensation will be made for the part of the study completed.

C. CONDITIONS OF PARTICIPATION

I understand that my participation is entirely voluntary and that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences. I further understand that all records and test results of this study will be kept strictly confidential. No one but the experimenters will have access to any information about me or my performance. In addition, my name will not be used in any report or publication.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

____
Name

____
Signature Date

____
Witness' signature Date

For further information about this study either before or after it is completed, please feel free to contact:
Dr. Virginia Penhune at 848-7535 (vpenhune@vax2.concordia.ca), or
Tal Savion-Lemieux at 848-7567 (t_savion@alcor.concordia.ca)

Appendix B

Music Questionnaire

Musical Training/ Experience

* Have you ever played a musical instrument (including voice/dance)? **YES** ☐ **NO** ☐

(The following questions are letter coded with respect to the first question, e.g. years of playing for instrument "a", instrument "b", etc.)

If yes, which instrument(s) (including voice/dance) in order of concentration: a) ________________________,
b) ____, c) ____

* How old were you when you first started playing/singing/dancing? a) _________, b) _________, c) _______

* How did you learn to play/sing/dance? a) _______________, b) _______________, c) _______________

* For how many years did you play/sing/dance?

0-3 yrs:	a) ☐	b) ☐	c) ☐
4-8 yrs:	a) ☐	b) ☐	c) ☐
9-13 yrs:	a) ☐	b) ☐	c) ☐
14 + yrs:	a) ☐	b) ☐	c) ☐

If stopped playing, at what age did you stop playing/singing/dancing? a) ______, b) _____, c) ______

* Are you currently practicing? a) YES ☐ NO ☐ b) YES ☐ NO ☐ c) YES ☐ NO ☐

If **yes**, how often do you practice?

0-1 times/wk:	a) ☐	b) ☐	c) ☐
2-3 times/wk:	a) ☐	b) ☐	c) ☐
4 +/wk:	a) ☐	b) ☐	c) ☐

If **yes**, approximately how many hours *per week* do you practice?

0-4 hrs/wk:	a) ☐	b) ☐	c) ☐
5-9 hrs/wk:	a) ☐	b) ☐	c) ☐
10-14 hrs/wk:	a) ☐	b) ☐	c) ☐
15-19 hrs/wk:	a) ☐	b) ☐	c) ☐
20-24 hrs/wk:	a) ☐	b) ☐	c) ☐
25 + hrs/wk:	a) ☐	b) ☐	c) ☐

If **no**, when did you stop practicing?

1 yr ago:	a) ☐	b) ☐	c) ☐
2 yrs ago:	a) ☐	b) ☐	c) ☐
3 yrs ago:	a) ☐	b) ☐	c) ☐
4 + yrs ago:	a) ☐	b) ☐	c) ☐

Do you read music? YES ☐ NO ☐

Musical Scale

1 – No musical training or experience
2 – < 3 yrs musical training or experience/no current practice (i.e. stopped practicing > 1 yr ago)
3 – < 3 yrs musical training or experience/current practice (i.e. been practicing > 2-3 times/wk in past yr)
4 – > 4 yrs musical training or experience/no current practice (i.e. stopped practicing > 1 yr ago)
5 – > 4 yrs musical training or experience/current practice (i.e. been practicing > 2-3 times/wk in past yr)