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The Effect of Sequential Stimuli Technique on Acquisition, Retention and Transfer of Ocular Motor Sequences Learning

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Abstract: In this research, the effect of sequential stimuli technique on acquisition, retention and transfer of motor sequences learning was examined. First, serial reaction time task was designed. 60 novice, right-handed subjects (15-18 years old, M±SD=17.27±2.87) participated in 5 groups including blocked-explicit, blocked-implicit, random-explicit, random-implicit and control group. All groups performed a pretest and then all participants (except the control group) took part in five training sessions; in each session, three blocks of ten trials according to related arrangement were performed. In explicit groups, participants were aware of the aim and arrangement of task while implicit groups were unaware. During the acquisition stage, control group was only in the lab environment. One day after the acquisition stage, participants took part in retention and transfer tests. The data were analyzed using student t, repeated measures and two-way analysis of variance tests. The findings showed a significant difference in the acquisition phase in accuracy and response time of blocks (each block consisted of ten trials) ($p>0.05$) but there was no significant difference among groups. However, implicit learning groups during research progressed as explicit learning groups; that explained the effectiveness of implicit knowledge in motor skills learning. As well, retention test showed that random practice was beter than blocked practice in movement accuracy but the type of practice did not have any effect on reaction time task. In transfer test, all groups showed transfer to novel sequence for response accuracy but they did not show transfer for response time. Overall findings of this research supported this idea that learning which occurs in the context of interference can show retention and transfer.

Key words: Practice method % Retention % Transfer % Motor sequence learning

INTRODUCTION

In daily life, a large range of motor skills can be learned simultaneously. A central question in the study of motor learning is how to structure practice of multiple skills in order to facilitate learning and retention. Previous work has shown that when more than one motor skill is learned in a single session, blocked practice leads to better acquisition, but random practice leads to better retention and transfer. This effect was first termed "contextual interference" by Battig (1972) in describing the results of verbal memory experiments and was then applied to the domain of motor learning by Shea and Morgan (1979) [1-3].

Manifestly humans have learned several skills and experiences from inception of life with many ways. One type of learning is motor sequence learning. Motor sequence is the focus of too much of human's intelligent behavior. It is well-known that such sequential skills involve chaining a number of primitive actions together. Thus motor sequence learning can be studied as a sample of motor learning. Motor sequence can be learned explicitly or implicitly. In explicit motor sequence learning, learner is aware of arrangement of sequence but in implicit one, she/he is unaware [4]. In explicit learning, memory is sued to examine real information; thus, for this type of learning working memory is essential, but in implicit learning, working memory is inactive and learner learns subjects and tasks unconsciously [5].

Many studies of motor sequence learning have looked at how a single novel sequence is acquired and retained over several training sessions [6, 7]. Commonly,

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learning has been characterized by three stages that correspond to specific points in the pattern of incremental changes that occur while practicing a new sequence [8, 9]. Within the first training session, fast and significant improvements in performance are observed typically over a relatively small number of practice trials. This stage is followed by slower and more gradual gains that take place over a number of days or weeks, leading to an eventual plateau in performance [6, 8, 10]. A third, intermediate stage, referred to as consolidation, has been the focus of much recent interest. This stage occurs between the first and second training sessions and is thought to be sleep-dependent [11, 12].

Support for the presence of separable stages of motor learning comes from functional imaging studies showing that different cortical and subcortical regions are preferentially activated at different stages of learning [13, 14].

It has been suggested that distribution of practice over time is important for a maximum benefit of practice to be gained, as the time delay allows for these neural changes to occur [6, 12]. Another important factor influencing how well a motor sequence is acquired and consolidated is the pattern of practice. This factor may be particularly relevant when learning more than one sequence, as is commonly the case in real life situations. Early studies of verbal memory in the 1960s revealed that practice in which learning trials were presented in a blocked order, where all trials of one task are learned together before those of a second one are introduced, resulted in better within-day acquisition but poorer retention and transfer to a novel task, compared to practice in which learning trials were presented in a random order [15]. This effect has been termed "contextual interference", as it was postulated that high degrees of interference during initial learning enhance across-day retention and transfer of learned skills to a novel task [1, 15]. Potential factors contributing to the contextual interference effect include, but are not limited to, the task and the practice schedule [2].

Two principal theories have been put forward to explain the contextual interference effect: The elaboration hypothesis (cited by Shea and Zimny 1983, 1988) [3] suggests that learning skills in a random fashion leads to more comprehensive and retrievable memories in the long term. The reconstruction hypothesis (cited by Lee and Magill 1985) [3] postulates that learning skills in a random manner requires the learner to actively reconstruct many action plans, which in turn leads to more effortful processing and a more permanent memory [3].

The majority of studies looking at contextual interference have focused on the learning of gross motor skills, whereas very few studies have looked at fine motor skill learning. Studying contextual interference may be especially relevant in settings in which optimal performance of fine motor movement is required, such as playing a musical instrument or response to special stimuli. Moreover, in one hand, at implicit learning, working memory is inactive and on the other hand, literatures of contextual interference emphasize that working memory is necessary to reconstruct action plans; nonetheless, Osaka (1997) (as cited in Magill and Hall, 1990) represented and expressed that conscious processes were not necessary for contextual interference effect and unconscious processes may contribute to that phenomena [1]. Therefore, the current study examined the effect of sequential stimuli technique on acquisition, retention and transfer of ocular motor sequences learning to compare explicit and implicit learning in the conditions of interference.

MATERIALS AND METHODS

Participants: The total sample was comprised of 60 healthy male students. All participants were between the ages of 15 and 18 years old. All participants were neurologically healthy and right-handed, as assessed using Mini mental state examination test (Fuleshtin, 1980) and General Health Questionnaire (Gold Berg, 1979).

In the first phase of research, software for the serial reaction time task in the C++ programming environment was designed. A computer company was requested to write and design serial reaction time task (SRT) instrument based on special characteristics. This software registered and recorded errors and response time (RT) automatically in response to sequential stimulus. It is a variant of the classical serial reaction time (SRT) task originally designed by Nissen and Bullemer (1987). Nissen and Bullemer (1987) designed a model in sequence learning and used this software to measure motor sequence learning and in many foreign studies this apparatus increasingly was employed and used for measurement of motor sequence learning. In this software, four square boxes were displayed on the center of the computer monitor (screen) that could change to yellow, green, red and blue colors and for each color there was a marked key on the keyboard. Participants were cued and instructed to press one of the four marked keys on keyboard, when visual stimuli were presented on the computer monitor.

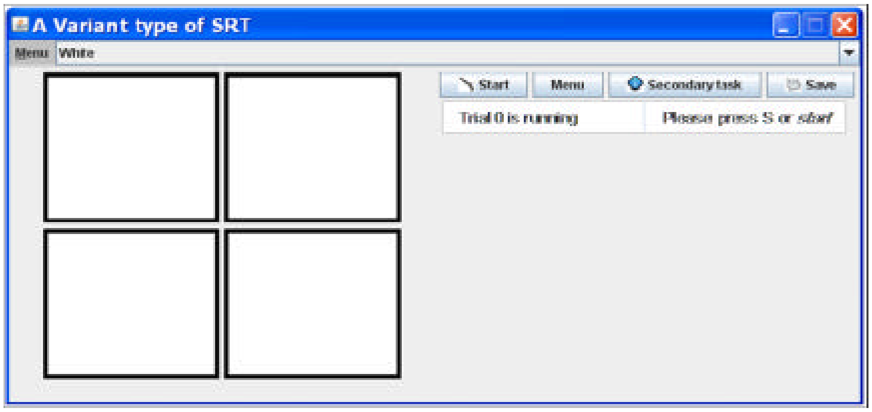

Fig. 1: General view for a variant type of SRT

In other words, stimulus appeared at one of four locations on the computer screen and the participant was required to press a key corresponding to that location as quickly as possible (Fig.1). In this software, each trial consisted of 8-element sequences that appeared sequentially and each block of practice included 10 trials (80 stimuli). To measure contextual interference effect, three sequences were employed and all were designed to be of equal difficulty (sequence A: yellow, green, yellow, blue, red, green, blue, red ; sequence B: blue, red, green, yellow, green, yellow, red, green; and sequence C; blue, yellow, blue, red, green, yellow, green, yellow). In addition, the same key was never pressed twice in succession. Breaks (60 seconds) were provided between blocks to prevent fatigue and optimize performance. A computer recorded all generated responses from the keyboard. A software written in C++ was used to create and control the presentation of the visual stimuli and automatically recorded the onset and offset of participants' key presses, which were subsequently used to calculate the indices of learning.

Participants were told that they would be learning different motor sequences, but only explicit groups were explicitly instructed about the sequences and implicit groups did not have any knowledge about sequences. Participants were asked to follow the stimuli as accurately as possible by pressing the key that corresponded to the location of the red illuminated rectangular bar. In order to minimize anticipatory responses and maximize response synchronization, participants were also instructed to synchronize their response with the visual stimulus by waiting until the red bar illuminated [16].

Procedure: Participants were divided into 5 groups including blocked-explicit, blocked-implicit, random-explicit, random-implicit and control group. All groups at first performed a pretest (three blocks of ten trials with random method) and then they (except control group) took part in five training sessions and in each session three blocks of ten trials according to related arrangements were performed. In explicit groups, participants were aware of the aim and arrangement of task but implicit groups were unaware. During acquisition phase, control group was only in the lab environment. This additional group was included to test the retention of three sequences without any interference. One day after the acquisition phase, participants took part in retention and transfer tests. On retention test, participants received three blocks of ten trials they had performed in pretest and in transfer phase, they received one block of a novel sequence. On each testing day, participants were first familiarized with the electronic keyboard and then computer-generated stimuli.

Blocked-explicit group during each session of training performed three blocks of ten trials with blocked method (i.e. all trials of each block began before another block was performed; for example A, B, C) and participants were aware of the aim and arrangement of sequences.

Blocked-implicit group performed like blocked-explicit group, but participants were unaware of the aim and arrangement of sequences.

Random-explicit group during each session of training performed three blocks of ten trials with random method (i.e. training of blocks were performed randomly; for example A, C, B) and participants were aware of the aim and arrangement of sequences.

Random-implicit group performed like random-explicit group, but participants were unaware of the aim and arrangement of sequences.

Learning was assessed by measuring changes in accuracy and response synchronization. Accuracy was scored individually by calculating the percentage of correct key presses made for each sequence type (i.e., A, B, or C) within each trial and block. Response synchronization was calculated for response time only; it characterized each participant's response time (ms) relative to the stimulus onset, averages of trials and blocks of practice for each type of sequence. Anticipatory responses were included in the measure (participants were asked to wait until the stimuli was illuminated by computer and then response) because previous studies have shown that anticipation increases with learning [6].

RESULTS

In pretest phase, to determine homogeneity of groups, two-way analysis of variance tests was used and results indicated no significant differences among groups in response synchronization (F=0.0001, P=0.99) and response accuracy (F=0.011, P=0.91) components and all groups were at the same level in motor performance. Paired t test showed no significant differences in the performance between pretest and retention test in the control group; therefore, a change in the performance of other groups was attributed to the effects of independent variables (type of learning, type of practice program).

Response synchronization in acquisition phase: analysis of variance with repeated measures (ANOVAs; Greenhouse-Geiser correction) indicated the significant main effect of block in response synchronization (F=2.158, P=0.43). It means that response time reduced by practicing. But there were no significant main effects of block-practice interaction, block-learning interaction and block-learning-practice interaction. However, there were no significant main effects and no interaction between block-learning, block-practice and block-learning-practice (p>0.05), but averages showed that performance in explicit groups was better than implicit groups and blocked practice was better than random practice in this phase of research (Table 1).

Response Accuracy in Acquisition Phase: Analysis of variance with repeated measures (ANOVAs; Greenhouse-Geiser correction) indicated a significant main effect of block on response accuracy (F=14.80, P=0.017). It means that accuracy increased by practicing. But there were no significant main effects of block-practice interaction, block-learning interaction and block-learning-practice interaction. However, there were no significant main effects and no interaction between block-learning, block-practice and block-learning-practice (p>0.05), but averages showed that performance in explicit groups was better than implicit groups and random practice was more accurate than blocked practice in this phase of research (Table 2).

Table 1: Analysis of variance with repeated measures for response synchronization component

Source	Sum of Squares	df	F	Sig.
Block factor	5.983710	6.474	2.158	*0.043
Block-Learning	4.483451	6.474	0.016	1.000
Block-Practice	2.591416	6.474	0.009	1.000
Block-Learning-Practice	2.18588	6.474	0.008	1.000

Table 2: Analysis of variance with repeated measures for response accuracy component

Source	Sum of Squares	df	F	Sig.
Block factor	407.90	3.19	14.80	*0.017
Block-Learning	0.706	3.19	0.026	0.99
Block-Practice	1.323	3.19	0.048	0.98
Block-Learning-Practice	0.747	3.19	0.027	0.99

Table 3: Two-way analysis of variance for response synchronization component in retention test

Source	Sum of Squares	df	F	Sig.
Learning factor	1.99617	1	0.019	0.89
Practice factor	6.39877	1	0.060	0.80
Interaction	534.760	1	0.083	0.96
Error	4.723364	44	………	…….

Table 4: Two-way analysis of variance for response accuracy component in retention test

Source	Sum of Squares	df	F	Sig
Learning factor	0.525	1	0.98	0.326
Practice factor	2.457	1	4.62	0.037*
Interaction	8.333	1	0.012	0.94
Error	0.532	44	………	…….

Retention Test: To examine performance in different states in retention test, two-way analysis of variance was used and results for two behavioral measures (response synchronization and response accuracy) were present as follows.

Table 3 showed no significant main effect between blocked and random practice in response time (response synchronization) but the average of the performances showed that performance in random practice was better than blocked practice. As well, there were no significant main effects of learning factor and interaction (i.e. interaction between learning factor and practice factor) and two types of learning performed similarly in this phase of research performed similarly in this phase of research (Table 3).

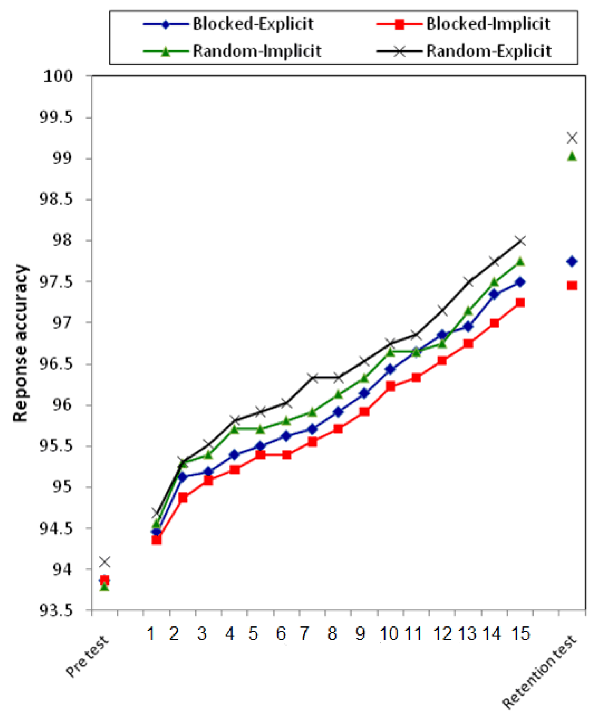

Fig. 2: Average accuracy for all conditions in acquisition and retention phase

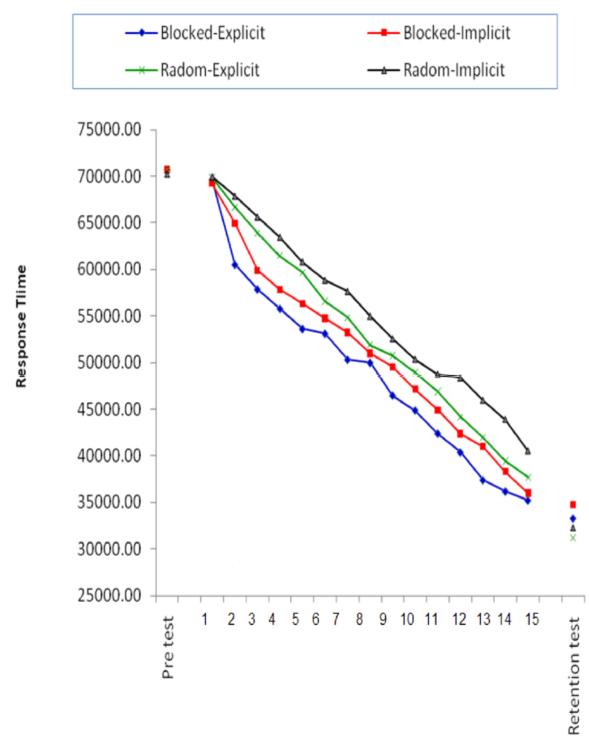

Fig. 3: Response synchronization for all conditions in acquisition and retention phase

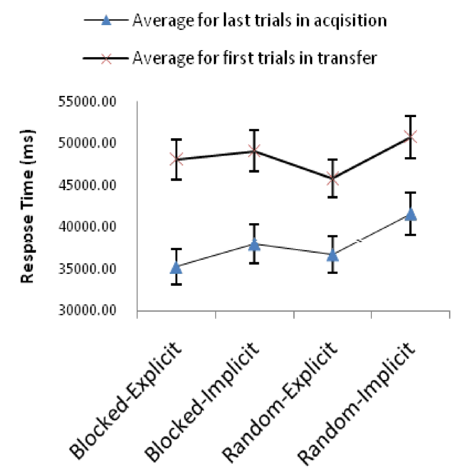

Fig. 4: Response synchronization for all conditions in transfer phase

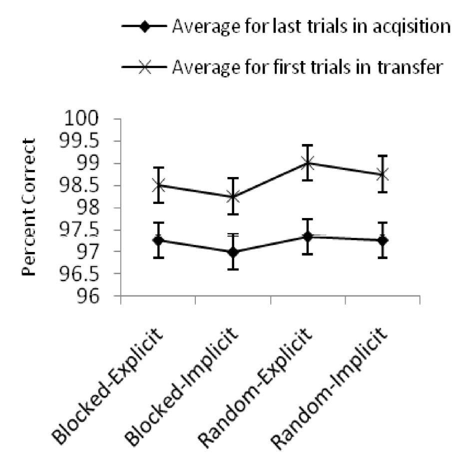

Fig. 5: Average accuracy for all conditions in transfer phase

Two-way analysis of variance for response accuracy component in retention test showed a significant main effect for practice factor and random practice was better than blocked practice in movement accuracy (Fig. 2 and Fig. 3).

Transfer: Performance on the three trial of the last block of practice in the acquisition phase was compared with the three trials of the first block of novel sequence in transfer phase in all four groups. For response accuracy (Fig. 4), there was a marginally significant main effect between two phases (acquisition and transfer) F (1, 44) = 35.95, P = 0.008 in such a way that participants in novel sequence were more accurate than the last block of practice in acquisition phase, indicating a certain degree of transfer. For response synchronization (Fig. 5), there was a marginally significant main effect between two phases (acquisition and transfer) F (1, 44) = 39.11, P = 0.011, this time showing better performance in the last block of practice in acquisition phase compared to novel sequence. Indicating a loss in performance and/or interference likely leads to negative transfer in this phase of research. No other significant main effects or interactions were found (P>0.325).

DISCUSSION AND CONCLUSION

The current study was motivated by early research findings from the contextual interference literature. Thus, in this experiment, we looked at the effect of sequential stimuli technique on acquisition, retention and transfer of ocular motor sequences learning. Overall, in acquisition phase, there were no significant main effects between two types of learning (explicit and implicit) and between two types of practice (blocked and random) but for response synchronization (measured by response time), blocked-explicit and blocked-implicit groups and then random-explicit and random-implicit groups considerably progressed in their performance. For response accuracy (measured by percentage of correct key presses), surprisingly, in acquisition phase, random practice groups (random-explicit and random-implicit) performed better than the blocked practice groups (blocked-explicit and blocked-implicit). In other words, massive practice led to enhanced sensory motor integration and timing (as measured by response synchronization), whereas random practice led to better stimulus-response association (as measured by response accuracy). In retention test, random practice (random-explicit and random-implicit) was better than blocked practice in movement accuracy but the type of practice did not affect reaction time task (response synchronization). Furthermore, all groups showed the transfer of learning to a novel sequence for response accuracy, but not response synchronization. Taken together, the overall pattern of results provided only partial support for the contextual interference hypothesis, with enhanced performance for response accuracy and response synchronization. Our findings are consistent with differential encoding of specific domains of motor performance and it is therefore suggested that the contextual interference hypothesis is rethought to take into account different measures of learning. Moreover, given that all groups showed retention, we postulated that the learning that occurs in the context of interference can show retention and transfer [17, 18].

An interesting and novel finding that has not been previously reported in the contextual interference literature is the dissociation we found between the behavioral measures used to assess learning and transfer. In many laboratory studies looking at contextual interference from a motor skill perspective, participants were required to move/respond as rapidly as possible [19, 20]. Thus, the dependent measure is often “response time”. In the present study, we broke down fine motor learning into two different components: accuracy, a component of the task that requires the association of the visual stimulus with the motor response and response synchronization, a component that requires fine-grained sensorimotor integration and timing. Interestingly, it was observed that practice pattern had a differential effect on the learning of these two measures, as we found that massed practice led to enhanced sensorimotor integration and timing, whereas random practice led to better stimulus-response association. We also showed transfer of learning to a novel sequence for response accuracy but not response synchronization, regardless of practice pattern. Taken together, these results supported the idea that different components of a motor skill are learned and transferred in different ways [21, 22].

Based on our findings, we proposed that learning the stimulus-response association is a fast process that benefits from structuring initial practice in a random fashion, because it requires the participant to acquire the stimulus-response association in multiple contexts by flexibly switching between the two sequences. Moreover, once the association has been learned, it seems to be resistant to interference and transferrable to a novel sequence. This is consistent with the elaboration or reconstruction hypotheses of contextual interference, but also applies to acquisition. On the other hand, learning of the sensorimotor integration and timing is a slower process that benefits from structuring initial practice in a blocked fashion, because practice in a single context allows for error-correction and fine-tuning of the response. Interestingly, this component of the task seems to be more resistant to transfer, because without a constant context, the fine timing of the response is difficult to acquire. One model that provides support for this dissociation is that of Hikosaka *et al*. (2002) [10].

This demonstrates that learning that occurs in the context of interference can show retention, which is not entirely consistent with previous studies showing a graded interference effect for consolidation and retention (Brashers Krug *et al*., 1996; Walker *et al*., 2003) [18, 17], but is consistent with Savion-Lemieux and Virginia B. Penhune (2010) and Sekiya (2007) [6,20]. Similar findings have been reported by Criscimangna-Hemminger (2008) and Shadmehr (2008), who proposed that with either enough practice or passage of time, motor memory becomes stable and less resistant to interference [23, 24].

In summary, the results of the present experiment represents a new way of understanding the effect of practice pattern on the acquisition, retention and transfer of visual-motor sequences. Overall, our results challenged the contextual interference hypothesis. It was therefore found out that the contextual interference effect is reconsidered at the behavioral measures level, such that each measure represents a component of sequence learning that can be differentially influenced by practice pattern. Based on the dissociation of our results for accuracy and response synchronization, it was postulated that learning the stimulus-response association is a fast and transferrable process that benefits from learning in multiple contexts. On the other hand, learning of the sensorimotor integration and timing aspects of the task is a slow process that is more resistant to transfer and that is promoted by learning in a single context that allows fine-tuning of the response. Regarding the results of the present experiment, overall, it can be stated that in teaching motor tasks, it is not necessary to explain the whole instructions for learning, because the learner can learn the task implicitly. Moreover, it is suggested to teachers and coaches use random practice in tasks with accuracy component and use blocked practice and emphasize this practice method in learning the sensorimotor integration and timing aspects.

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