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Original Article

Effectiveness of motor sequential learning according to practice schedules in healthy adults; distributed practice versus massed practice

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Abstract. [Purpose] The purpose of the current study was to compare the effectiveness of motor sequential learning according to two different types of practice schedules, distributed practice schedule (two 12-hour inter-trial intervals) and massed practice schedule (two 10-minute inter-trial intervals) using a serial reaction time (SRT) task. [Subjects and Methods] Thirty healthy subjects were recruited and then randomly and evenly assigned to either the distributed practice group or the massed practice group. All subjects performed three consecutive sessions of the SRT task following one of the two different types of practice schedules. Distributed practice was scheduled for two 12-hour inter-session intervals including sleeping time, whereas massed practice was administered for two 10-minute inter-session intervals. Response time (RT) and response accuracy (RA) were measured in at pre-test, mid-test, and post-test. [Results] For RT, univariate analysis demonstrated significant main effects in the within-group comparison of the three tests as well as the interaction effect of two groups × three tests, whereas the between-group comparison showed no significant effect. The results for RA showed no significant differences in neither the between-group comparison nor the interaction effect of two groups × three tests, whereas the within-group comparison of the three tests showed a significant main effect. [Conclusion] Distributed practice led to enhancement of motor skill acquisition at the first inter-session interval as well as at the second inter-interval the following day, compared to massed practice. Consequentially, the results of this study suggest that a distributed practice schedule can enhance the effectiveness of motor sequential learning in 1-day learning as well as for two days learning formats compared to massed practice.
Key words: Distributed practice, Massed practice, Spacing effect

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INTRODUCTION

Motor skill learning has become an important issue, due to the increasing involvement of human movement behaviors in neuroscience, psychology, and physical education[1–5]. However, until now, motor learning has puzzled contemporary science, and its mechanisms and contributing factors remaining unclear. How motor skills are acquired and processed by the neuromuscular system has become a topic of interest. Furthermore, application methods for improving motor skills have been spotlighted in order to increase the capability of motor performance[2, 6–8]. Several factors related to motor learning are already well known, in terms of amount of practice, types of feedback, application period of feedback, practice schedule, and so forth[9–12].

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It is well known that the effectiveness of motor learning can vary according to the practice schedule. Of these schedule types, distributed and massed practice schedules are common in learning studies. Distributed practice utilizes temporal spacing intervals between repetition of tasks usually of the order of hours or during a few days, whereas massed practice consists of fewer and shorter inter-trial intervals during training sessions[11, 13–15]. In general, motor skills are more effectively learned when there is a long resting time between training intervals, a phenomenon called the spacing effect[11, 13–16]. Based on this, many studies have tried to identify the exact temporal period of inter-trial interval that maximize the effectiveness of motor skill learning[14, 17].

Traditionally, research on the spacing effect has been performed in the field of experimental psychology, focusing on areas of memory and verbal learning[18, 19]. To the best of our knowledge, few studies have investigated whether motor skill acquisition is more effective using distributed practice or massed practice. In addition, there has been no consistent finding regarding inter-trial intervals between repetition of tasks among previous studies[14, 15, 20]. In this study, we compared motor skill learning between 1-day learning and for two days learning formats as well as the effectiveness of motor sequential learning of a serial reaction time (SRT) task according to practice schedules, i.e., distributed practice for two days versus massed practice in 1-day learning formats.

SUBJECTS AND METHODS

Thirty healthy subjects were recruited based on the following inclusion criteria: (1) no previous history of neurological or psychiatric disorders, (2) no pathology of musculoskeletal function in the upper limb, (3) right-handed as verified by the modified Edinburgh Handedness Inventory, (4) no previous exposure to other sequential learning experiments within the past 6 months. All subjects were randomly and evenly assigned to the distributed practice group or massed practice group. Subjects in the distributed group did not suffer from sleep disturbance during the practice session. All subjects understood the purpose of the study and gave their written, informed consent to participation. This study was approved by the Institutional Review Board of the local ethics committee in accordance with the ethical principles of the Declaration of Helsinki.

The SRT task was performed with a computer using stimulus presentation software program (LAXTHA, Korea), which is composed of visual cues that assess the response time and accuracy in performing a task. The visual cues were eight non-colored Arabic numbers randomly presented in the center of a computer monitor in consecutive order without auditory cues. When a visual cue (i.e. one, two, three, four, five, six, seven, and eight) appeared to a subject, at the start of each trial, the subject selected the appropriate response key, which ended the trial. At the end of each trial, there was a short fixed delay before another cue was displayed. The SRT task for training consisted of three sessions, 12 blocks, and 864 trials. One session included a total of four blocks with a resting time of 60 seconds between each block. One block consisted of total 72 trials, which were randomly presented with equal probabilities of 12.5% for each of the eight cues. Thus, each cue was presented nine times in one block, and it remained on the monitor until 1,000 milliseconds had elapsed regardless of the subject's response. The default inter-stimuli interval was 500 milliseconds and was independent of the response time. Thus, each subject usually spent under 10 minutes carrying out one session.

All subjects sat in front of a table with their right elbow flexed at approximately 90°. Their right hand was placed on the response keys, which were composed of left, right, up, and down arrows on the computer keyboard. For performance of the SRT task, subjects were instructed to respond to each cue with a predetermined set of response keys: the "one" or "eight" numbers meant that the subject had to press the "←" button with the index finger, the "two" or "seven" numbers indicated the "↑" button should be pressed with the middle finger, the "three" or "six" numbers indicated the "→" button should be pressed with the ring finger, and the "four" or "five" numbers indicated the "↓" button should be pressed with the middle finger. Following the visual cues, all subjects were asked to press the button as quickly as possible according to the corresponding cues using the dominant right hand.

The experimental paradigm consisted of three consecutive training sessions (i.e., first-session, second session, and third session) and three tests to assess response time and accuracy (i.e., pre-test, mid-test immediately after the second session, post-test immediately after the third session). All subjects were asked to perform a total of three training sessions, with different spacing gaps according to their designated practice type, that were identical in the composition of the SRT task. Subjects belonging to the distributed practice group were allowed a resting time of 12 hours between sessions, including sleeping time, whereas subjects in the massed practice group were provided a resting time of 10 minutes between sessions. In addition, subjects in the distributed practice group were instructed not to ingest alcohol or caffeine during the training session. One demonstration and trial for each block of the SRT task with a different sequence were presented prior to the actual experiment until they became familiar with the task and experimental procedure.

Participants were not given the sequence information and were asked for the correct sequence based on memory only after the experiment in order to measure passive motor sequential learning. No one remembered the correct sequence in its entirety after the end of the experiment. The response time from presentation of the visual stimuli to motor response was measured in milliseconds, and the response accuracy was analyzed by percentile as the proportion of correct responses in presented total stimuli in the pre-test, mid-test, and post-test.

The χ^2 test was used to compare the gender difference of the distributed practice group and the massed practice group. The independent t-test was performed to analyze differences in demographic (i.e., age) and dependent variables (i.e., response time and response accuracy) in the first test between the two groups. Separate univariate analyses of variance were carried out to compare between-group and group changes using 2 (groups: distributed practice group, massed practice group) × 2 (test sessions: pre-test and mid-test or pre-test and post-test) ANOVA with repeated measures. PAWS, version 18.0 (SPSS Inc., USA) was used for all statistical analyses, and differences with a p value lower than 0.05 were regarded as significant.

RESULTS

Improved motor response time and accuracy were observed in both practice groups, indicating successful motor learning during the three training sessions. In the demographic data, no significant differences were observed in terms of gender (distributed practiced group; men=7, women=8, massed practice group; men=9, women=6, p=0.715) or age (distributd practiced group; 22.07±1.94, distributed practiced group; 22.47±2.07, p=0.589). There were also no significant differences between the groups in the dependent variables of response time (RT) and response accuracy (RA) in the pre-test (RT; p=0.697, RA; p=0.748). Table 1 shows the changes in RT and RA in the distributed practice group and massed practice group (Table 1).

For RT, univariate analysis showed no significant difference in the between-group comparison ($F_{(1,28)}$=1.405, p=0.246). However, the significant main effects in the within-group comparison of the three tests ($F_{(2,28)}$=70.805,

Table 1. Changes in response time and accuracy in response to visual stimuli in the distributed practice group and the massed practice group

	Distributed practice			Massed practice		
	Pre-test	Mid-test	Post-test	Pre-test	Mid-test	Post-test
Response time (ms)	674.2±51.5	585.6±57.8	577.3±69.2	675.5±59.2	625.5±48.1	602.9±52.8
Response accuracy (%)	67.3±20.0	90.4±6.0	90.4±4.9	70.2±16.7	85.2±9.8	89.0±8.9

p=0.000) and the interaction effect of group × three tests ($F_{(2,28)}$=3.310, p=0.044) were observed. In the test of within group contrasts, a significant interaction effect of group × pre-/mid-tests was observed ($F_{(2,28)}$=7.100, p=0.013), whereas there was no significant interaction effect of group × mid-/post-tests ($F_{(2,28)}$=1.512, p=0.229).

For RA, there was no significant difference in the between-group comparison ($F_{(1,28)}$=0.146, p=0.706) nor in the interaction of group × three tests ($F_{(2,28)}$=2.085, p=0.160). However, there was a significant main effect of the within-group comparison of the three tests ($F_{(2,28)}$=38.917, p=0.000). In the test of within group contrasts, a significant main effect in the within-group comparison between the first and second session was found ($F_{(2,28)}$=45.533, p=0.000), but there was no significant effect in the within-group comparison between the second and third session ($F_{(2,28)}$=1.128, p=0.297).

DISCUSSION

In the current study, we compared the effectiveness of motor sequential learning between a distributed practice schedule (two 12-hour inter-trial intervals) and a massed practice schedule (two 10-minute inter-trial intervals) using SRT task. Our results show that, distributed practice consisting of inter-trial intervals of 12 hours more effectively enhanced motor skill acquisition than massed practice consisting of inter-trial intervals of 10 minutes. Distributed practice, in which the third trial was performed on the following day, improved motor sequential learning more than massed practice, in which the trials were performed provided in a 1-day learning format. Consequently, we confirmed that a distributed practice schedule better enhances motor sequential learning in both 1-day learning and for two days learning formats than a massed practice schedule.

The benefits of distributed practice have been researched since the late 1800s[11)]. It is well established that distributed practice has advantages in terms of both implicit and explicit memories, basic memory tasks using words, educational materials, motor skill acquisition, and so forth[12, 21, 22)]. Despite abundant evidence that distributed learning has benefits for memory and learning, studies of distributed learning in the context of procedural learning or motor sequence acquisition are relatively few. Shea et al[14)]. used three variations of a key-press timing task, similar to our experimental design, and found that the spacing gap in distributed practice scheduled within 1-day and during a few days intervals enhanced motor performance in a delayed retention test. In addition, their other experiment using a dynamic balance task provided the same result regarding the comparison of distributed and massed practice. Previous studies have also suggested the benefits of distributed practice in various procedural motor tasks, in terms of surgical skill training using virtual reality, and discrete motor tasks, etc[20, 23, 24)]. Likewise, prior studies corroborate our findings, showing that inter-trial intervals play an important role in learning motor skills[12–14, 16, 22)].

To explain the benefits of distributed practice, a theory of memory consolidation has been proposed[14, 25)]. Memory consolidation is a term used as a category of processes in which a memory trace is stabilized from a relatively unstable phase into a permanent form[14, 26, 27)]. Previous studies have argued that a relatively longer inter-trial interval provides the opportunity for memory consolidation without interruption from additional practice[14, 28)]. Memory consolidation requires a substantial period of time with no disruptions. In addition, Karni et al[29)]. suggested that relatively long periods of rest and sleep between training sessions might improve motor performance. Thus, our findings that distributed practice within 1-day and for two days intervals led to faster and more accurate motor responses in the SRT task than massed practice can be attributed to the improvement of explicit and implicit memory retention upon completion of memory consolidation. However, our results also show that motor performance between the first and second session within 1-day improved more than that between the second and third sessions which were performed on different days. This result may be due to a celling effect. Our SRT task paradigm was not complex, therefore as a long period of skill acquisition was not required. Thus, we assume that our participants almost reached their maximal learning capacity in the second training session.

Motor skill learning is an essential component for successfully performing physical activities in daily life[2)]. Understanding the mechanisms of motor learning in the human nervous system remains an interesting scientific issue in neuroscience. Numerous prior studies have attempted to determine the factors that can enhance the acquisition and retention of motor skills[2, 30, 31)]. In particular, it is important to increase the effectiveness of motor skill learning in the fields of neurological rehabilitation and sport science. Therefore, we expect that these findings will help to develop efficient and effective approaches for the facilitation of motor learning. However, this study had some limitations. Retention of motor skills was not measured, and the amount of sleep the previous night was not controlled. It is already known that implicit and explicit learning are affected by sleep. In the future, studies will be required to take these elements into consideration.

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REFERENCES

1) Nielsen JB, Cohen LG: The Olympic brain. Does corticospinal plasticity play a role in acquisition of skills required for high-performance sports? J Physiol, 2008, 586: 65–70. [Medline] [CrossRef]
2) Schmidt RA, Lee TD: Motor learning and performance; From principle to application. Human Kinetics, 2014.
3) Kwon YH, Chang JS, Lee MH, et al.: Evidence of neuromuscular adaptation according to motor sequential learning in the serial reaction time task. J Phys Ther Sci, 2010, 22: 117–121. [CrossRef]
4) Kwon YH, Kwon JW: Response inhibition induced in the stop-signal task by transcranial direct current stimulation of the pre-supplementary motor area and primary sensoriomotor cortex. J Phys Ther Sci, 2013, 25: 1083–1086. [Medline] [CrossRef]
5) Kwon YH, Park JH: Changes in cerebral and cerebellar activation patterns induced by short-term sequence learning of a serial reaction time task: an fMRI study. J Phys Ther Sci, 2013, 25: 505–508. [CrossRef]
6) Stickgold R: Sleep-dependent memory consolidation. Nature, 2005, 437: 1272–1278. [Medline] [CrossRef]
7) White O, Diedrichsen J: Flexible switching of feedback control mechanisms allows for learning of different task dynamics. PLoS ONE, 2013, 8: e54771. [Medline] [CrossRef]
8) Frank C, Land WM, Popp C, et al.: Mental representation and mental practice: experimental investigation on the functional links between motor memory and motor imagery. PLoS ONE, 2014, 9: e95175. [Medline] [CrossRef]
9) Ma EP, Yiu GK, Yiu EM: The effects of self-controlled feedback on learning of a “relaxed phonation task”. J Voice, 2013, 27: 723–728. [Medline] [CrossRef]
10) Vieira MM, Ugrinowitsch H, Oliveira FS, et al.: Effects of knowledge of results (KR) frequency in the learning of a timing skill: absolute versus relative KR frequency. Percept Mot Skills, 2012, 115: 360–369. [Medline] [CrossRef]
11) Cepeda NJ, Pashler H, Vul E, et al.: Distributed practice in verbal recall tasks: a review and quantitative synthesis. Psychol Bull, 2006, 132: 354–380. [Medline] [CrossRef]
12) Benjamin AS, Tullis J: What makes distributed practice effective? Cognit Psychol, 2010, 61: 228–247. [Medline] [CrossRef]
13) Goedert KM, Miller J: Spacing practice sessions across days earlier rather than later in training improves performance of a visuomotor skill. Exp Brain Res, 2008, 189: 189–197. [Medline] [CrossRef]
14) Shea CH, Lai Q, Black C, et al.: Spacing practice sessions across days benefits the learning of motor skills. Hum Mov Sci, 2000, 19: 737–760. [CrossRef]
15) Cepeda NJ, Coburn N, Rohrer D, et al.: Optimizing distributed practice: theoretical analysis and practical implications. Exp Psychol, 2009, 56: 236–246. [Medline] [CrossRef]
16) Seabrook R, Brown GD, Solity JE: Distributed and massed practice: from laboratory to classroom. Appl Cogn Psychol, 2005, 19: 107–122. [CrossRef]
17) Greene RL: Human memory: Paradigms and paradoxes. Hillsdale: Erlbaum, 1992.
18) Ebbinghaus H: Memory: A contribution to experimental psychology. New York: Dover Publications, 1964.
19) Jost A: Die Assoziations Festigkeit in ihrer Abhängigkeit 712 von der Verteilung der Wiederholungenions [The strength of 713 associations in their dependence on the distribution of 714 repetitions]. Z Psychol Physiol Sinnesorgane, 1897, 14: 436–472.
20) Dail TK, Christina RW: Distribution of practice and metacognition in learning and long-term retention of a discrete motor task. Res Q Exerc Sport, 2004, 75: 148–155. [Medline] [CrossRef]
21) Krug D, Davis TB, Glover JA: Massed versus distributed repeated reading: a case of forgetting helping recall? J Educ Psychol, 1990, 82: 366–371. [CrossRef]
22) Lee TD, Genovese ED: Distribution of practice in motor skill acquisition: different effects for discrete and continuous tasks. Res Q Exerc Sport, 1989, 60: 59–65. [Medline] [CrossRef]
23) Mackay S, Morgan P, Datta V, et al.: Practice distribution in procedural skills training: a randomized controlled trial. Surg Endosc, 2002, 16: 957–961. [Medline] [CrossRef]
24) Donovan JJ, Radosevich DJ: A meta-analytic review of the distribution of practice effect: now you see it, now you don’t. J Appl Psychol, 1999, 84: 795–805. [CrossRef]
25) Brashers-Krug T, Shadmehr R, Bizzi E: Consolidation in human motor memory. Nature, 1996, 382: 252–255. [Medline] [CrossRef]
26) Dudai Y: The neurobiology of consolidations, or, how stable is the engram? Annu Rev Psychol, 2004, 55: 51–86. [Medline] [CrossRef]
27) Shadmehr R, Brashers-Krug T: Functional stages in the formation of human long-term motor memory. J Neurosci, 1997, 17: 409–419. [Medline]
28) Baddeley AD, Longman JA: The influence of length and frequency of training session on the rate of learning to type. Ergonomics, 1978, 21: 627–635. [CrossRef]
29) Karni A, Tanne D, Rubenstein BS, et al.: Dependence on REM sleep of overnight improvement of a perceptual skill. Science, 1994, 265: 679–682. [Medline] [CrossRef]
30) Kwon YH, Kwon JW, Park JW: Changes in brain activation patterns according to cross-training effect in serial reaction time task: an functional MRI study. Neural Regen Res, 2013, 8: 639–646. [Medline]
31) Kwon YH, Nam KS, Park JW: Identification of cortical activation and white matter architecture according to short-term motor learning in the human brain: functional MRI and diffusion tensor tractography study. Neurosci Lett, 2012, 520: 11–15. [Medline] [CrossRef]