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Original Article

Does an interference task immediately after practice prevent memory consolidation of sequence-specific learning?

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Abstract. [Purpose] Learning of movement procedures (sequence learning) is essential in physical therapy. Studies have shown that sequence-specific learning may be integrated from an early stage. This study examines the effect of an interference task on the retention of sequence-specific learning. [Participants and Methods] Young adults were randomly divided into a control group and an interference task group, and two experiments were performed. In each experiment, the control group practiced task A in both the acquisition phase and the retention phase four to five hours later. The Interference group practiced task A in the acquisition phase followed by task B, which is similar to the interference task, and then performed task A in the retention phase four to five hours later. In Experiment 2, the amount of practice for task A in the practice phase was 25% of that in Experiment 1. [Results] Sequence-specific learning occurred in the early stages of practice. In particular, the performance of Experiment 1 reached the ceiling. The results of the retention test showed no significant interference effect due to similar tasks. [Conclusion] Implicit sequence-specific learning stabilizes performance early and is not affected by interference tasks.
Key words: Implicit learning, Sequence learning, Interference task

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EXPERIMENT 1

INTRODUCTION

Physical therapists often use verbal instructions to teach patients how to move. Moreover, patients improve their movement based on this explicit knowledge. However, there is another learning mode in motor learning that does not rely on explicit knowledge. This type of learning, called implicit learning, was defined by Kleynen et al.[1)] as “learning which progresses with no or minimal increase in verbal knowledge of movement performance (e.g., facts and rules) and without awareness”. In the past, the serial reaction time (SRT) task was the primary paradigm of implicit learning evaluation[2)]. However, the alternating serial reaction time (ASRT) task has recently become an alternative method[3–9)]. In a typical ASRT task, learners practice skills to respond as quickly as possible to the four possible stimuli requiring different responses on the computer screen. The continuous stimuli used include combinations that appear frequently. Learners can react quickly to high-frequency stimulus combinations than low-frequency stimulus combinations, even though they are unaware of the difference in stimulus frequency. In many studies of implicit learning, ASRT tasks made it possible to distinguish between task-specific (specific

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sequence) and general (key press) learning[6, 10]. Long-term retention of learned motor skills requires time for consolidation (offline learning)[11–14]. Furthermore, motor skills memory is most unstable four to six hours after practice[13–16]. Therefore, if learners perform similar motor skills as an interference task after practice, memory consolidation is impaired[15–17]. Kobor et al.[18] used an interference task to test the consolidation and long-term retention in implicit learning. However, because they inserted the interference task 24 hours and one year later, learners performed memory consolidation. Therefore, we verified the effect of the insertion of an interference task immediately after the practice of the ASRT task on the retention of implicit learning.

PARTICIPANTS AND METHODS

Twenty-two young adults (9 females, 13 males; mean age=24.7 years, SD=2.5) participated in this study. We excluded participants who had visual, musculoskeletal, or neurological problems. All the participants provided written informed consent prior to the experiments. The task was to press the keys corresponding to the stimuli continuously presented on the display as quickly and accurately as possible with the index and middle fingers of both hands (Figs. 1, 2). The equipment used in the experiment was a laptop computer (Panasonic CF-XZ, Osaka, Japan) and a response pad (Cedrus RB-740, San Pedro, CA, USA). In addition, we used a custom-built program (Cedrus SuperLab 6.0, San Pedro, CA, USA) for ASRT task. The participants sat in front of a laptop computer and a response pad. We set the laptop computer to display the stimulus within a 3.8° horizontal direction[19]. In addition, the display angle was adjusted to enable the participant to easily see it. The four keys on the reaction pad were set to 1, 2, 3, and 4 in order from the left, with each key assigned a finger (key 1: left middle finger, key 2: left index finger, key 3: right index finger, key 4: right middle finger). One of the four white circles placed horizontally on the computer screen turned into a black circle (Fig. 1). The participants were required to press the key corresponding to the position of the black circle as quickly and accurately as possible. One block consisted of 84 stimuli. The first four stimuli of the block were randomly displayed from 1 to 4. Subsequently, an alternating sequence of eight elements was repeated 10 times. The alternating sequence was "3R1R2R4R" for task A and "4R2R1R3R" for task B (R was displayed randomly from 1 to 4). When the participant responded to the stimulus and pressed a key, the stimulus disappeared once, and the next stimulus was displayed 120 ms later. We instructed the participants to maintain a correct response rate of 92–93%. After one block of the task, they were given feedback on the computer screen according to the correct response rate (91% or less: "be more aware of accuracy"; 94% or more: "be more aware of speed").

We randomly assigned the participants to two groups: the interference task group (n=11) and the control group (n=11). In the acquisition phase, both groups practiced task A (20 blocks). Immediately afterward, the interference task group performed task B (five blocks) as an interference task. Finally, in both groups, task A (five blocks) was performed as a retention test four to five hours after the acquisition phase (Fig. 2). According to a previous study, after the retention test, the participants were asked to answer the following questions to evaluate whether they had explicit knowledge of the sequence peculiar to

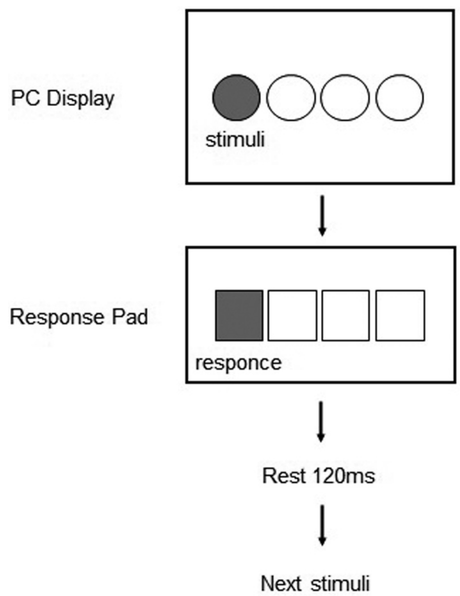

Fig. 1. ASRT task. The response pad connects to a personal computer. Four white circles are displayed on the computer screen. One of these four circles turns black as a stimulus. Participants were required to press the keys on the response pad corresponding to this stimulus as quickly and accurately as possible. The next stimulus was presented 120 ms after the participant had pressed the key in response to the previous stimulus.

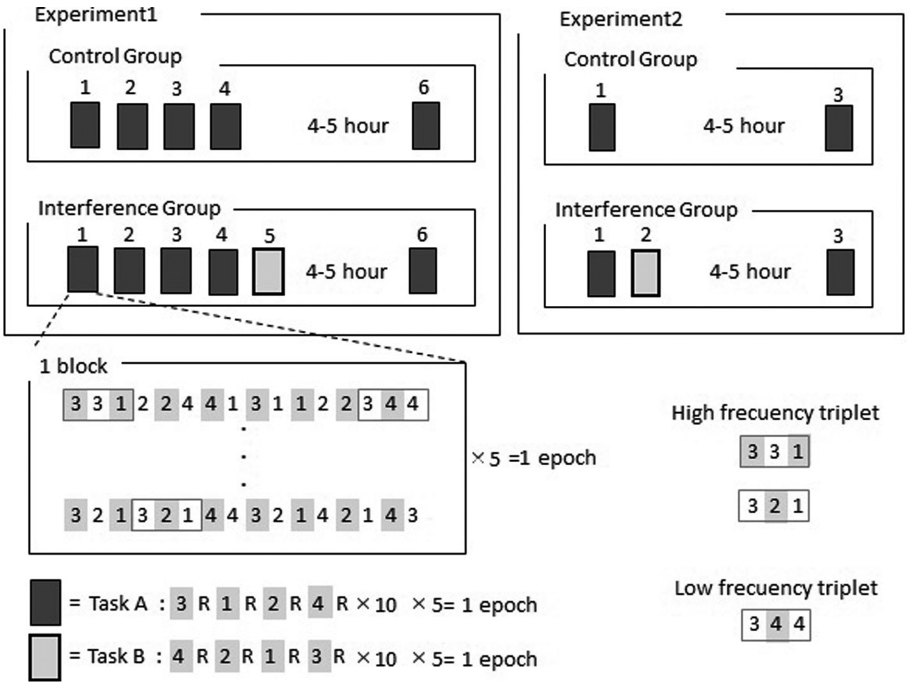

Fig. 2. Experimental design. One block consisted of eight stimuli repeated ten times. One epoch consists of five blocks. There were two tasks to be performed: task A (3R1R2R4R) and task B (4R2R1R3R). R was set to display one of the Stimuli 1–4. A triplet consists of a sequence of three stimuli. Some triplets in the task had a high frequency of occurrence, and some had a low frequency of occurrence.

task A[4, 20]. (1) “Do you have anything to report regarding the task?” (2) “Did you notice anything special about the task or the materials?” (3) “Did you notice any regularity in the way the stimulus was moving on the screen?”

Data processing and statistical analyses were based on previous studies[3, 6, 8]. We divided the alternating sequence into triplets and analyzed them to evaluate sequence-specific learning. As the alternating sequence was “3R1R2R4R” for task A, some triplets appeared more frequently than others. The appearance rate of 3_1, 1_2, 2_4, and 4_3 triplets (where _ is an arbitrary number) was 62.5% and is referred to as high-frequency triplets. The remaining 37.5% were called low-frequency triplets[5, 6]. Furthermore, repetitions, such as 111 and 333, and trills, such as 232 and 434, were excluded from the low-frequency triplets. We defined the reaction time as the difference between the triplet’s second and third reactions, and calculated the mean and standard deviation. Finally, we used the double standard deviation as the cutoff value for outliers[21]. Following previous studies, we defined the differences in reaction time between the high-frequency triplets and the low-frequency triplets as a sequence-specific learning measure[3, 7, 20, 22]. We defined five blocks of tasks as an epoch for data processing. Therefore, in the acquisition phase, one to five blocks were epoch 1, six to ten blocks were epoch 2, the interference task was epoch 5, and the retention test was epoch 6. The average reaction times (RT) for high-frequency and low-frequency triplets (as the dependent variable) was calculated for each participant and epoch. A repeated measures analysis of variance (ANOVA) was conducted with GROUP (control vs. interference) as the between-subject factor and EPOCH (from one to four, and six) and TRIPLET TYPE (high frequency vs. low frequency) as the within-subject factor to test the learning effects. A post hoc analysis was conducted using the Bonferroni method. In addition, multiple comparisons were performed on the difference in reaction time among all epochs (including epoch 5) in the interference group to test the effect of the interference task. Statistical significance was set at $p<0.05$. All analyses were conducted in SPSS (version 26, IBM).

This study was approved by the Research Ethics Board of the International University of Health and Welfare (Approval No. 19-Ig-203).

RESULTS

According to the responses to the question after the retention test, no participant noticed the sequence-specific task. Table 1 shows the reaction times for each epoch in both groups. In both groups, the RT of each triplet decreased during the practice phase. Furthermore, in all epochs, the RT of the high-frequency triplets was shorter than that of the low-frequency triplets. We conducted a three-way ANOVA for the reaction time on GROUP, EPOCH, and TRIPLET TYPE and identified significant main effects in the EPOCH ($F=28.46$, $p<0.001$) and TRIPLET TYPE ($F=100.72$, $p<0.001$). No significant interaction was

Table 1. Reaction times of triplet in each group (Experiment 1) (Unit: ms)

	epoch 1	epoch 2	epoch 3	epoch 4	epoch 5	epoch 6
Control-High	411 ± 60	369 ± 35	360 ± 36	357 ± 36		349 ± 26
Control-Low	424 ± 63	391 ± 35	381 ± 32	382 ± 26		371 ± 19
Interference-High	398 ± 28	375 ± 22	365 ± 19	358 ± 22	374 ± 20	363 ± 27
Interference-Low	418 ± 31	397 ± 29	387 ± 27	385 ± 25	381 ± 29	376 ± 33

observed. The post hoc analysis showed significant differences in RT among epochs (epoch 1 >epoch 2, 3, 4, 6, epoch 2 >epoch 6, $p<0.01$). Multiple comparisons of the RT differences between epochs (including epoch 5) in the interference group showed significant differences (epoch 3 >epoch 5, epoch 4 >epoch 5, $p<0.05$).

DISCUSSION

The participant's answer to the question after the retention test and the reaction time of the high-frequency triplet was shorter than the low-frequency reaction time, thus indicating that the person performed implicit sequence-specific learning[4, 20)]. This result was the same as that of previous studies[3, 7, 20, 22)] that performed a similar procedure. As a result of the ANOVA, no interaction was observed, even though the main effects of the epoch and triplet were significant. This result indicates that interference by task B did not occur in the interference group. In other words, task A did not interfere with task B because it was already integrated when task B was inserted. An explanation is that overlearning occurred. Overlearning is defined as "continuous training conducted after performance improvement has been maximized[23)]". The ANOVA results showed a difference in reaction time between the high- and low-frequency triplets at epoch 1. One epoch of task A contained the sequence "3R1R2R4R" 50 times. Since the practice was a repetition of 200 sequences, sequence-specific learning had already been performed in the first 25% stage. The ceiling, at which point the reaction time is constant after the second block, indicates that this practice is overlearning. This overlearning rapidly stabilized the performance of task A, and, as a result, the participants acquired resistance to task B[23, 24)]. Therefore, sequence-specific learning of the ASRT task was found to have occurred in the early stage of practice, and the learned performance could have been stabilized by overlearning. In addition, the ASRT task practice procedures performed in previous studies[9, 20)] are likely to have been overlearning. Therefore, to accurately investigate the consolidation of sequence-specific learning, a design different from previous research, such as inserting an interference task at the stage where overlearning does not occur, is required.

EXPERIMENT 2

INTRODUCTION

Since the possibility of overlearning in Experiment 1 makes it difficult to study sequence-specific learning consolidation, an experiment, where an interference task is inserted, is required before overlearning occurs. Furthermore, the results of Experiment 1 suggest that overlearning appears after epoch 2 of the acquisition phase. Therefore, in Experiment 2, we inserted an interference task after epoch 1 of the acquisition phase to examine the effect on the retention of sequence-specific learning.

PARTICIPANTS AND METHODS

Fifteen young adults (3 females, 12 males; mean age=21.1 years, SD=0.3) participated in this study. We excluded participants who had visual, musculoskeletal, or neurological problems. All participants provided written informed consent prior to the experiments. We randomly assigned the participants to two groups: the interference task group (n=8) and the control group (n=7).

The experimental apparatus was identical to that used in Experiment 1. The contents of tasks A and B were the same as in Experiment 1, but both groups practiced only five blocks of task A in the acquisition phase. The procedures for task B as an interference task and task A as a retention task were similar to that in Experiment 1.

We performed a repeated-measures ANOVA with GROUP (control vs. interference), EPOCH (epoch 1 vs. epoch 3), and TRIPLET TYPE (high-frequency vs. low-frequency) to test the learning effects. Statistical significance was set at $p<0.05$.

RESULTS

According to the responses to the question after the retention test, no participant noticed the sequence-specific task. In epoch 1, the reaction time of the high-frequency triplet was shorter than that of the low-frequency triplet (Table 2). Moreover,

Table 2. Reaction times of triplet in each group (Experiment 2) (Unit: ms)

	epoch 1	epoch 2	epoch 3
Control-High	398 ± 42		363 ± 27
Control-Low	425 ± 46		387 ± 22
Interference-High	381 ± 19	365 ± 26	350 ± 24
Interference-Low	407 ± 24	382 ± 27	376 ± 23

the reaction time of epoch 3 was faster than that of epoch 1. A repeated measures ANOVA showed a significant main effect on TRIPLET TYPE ($F=124.43$, $p<0.001$) and EPOCH ($F=76.43$, $p<0.001$), but no significant interaction.

DISCUSSION

The fast reaction times of the high-frequency triplets and the responses to the questionnaire indicate that the participants implicitly performed sequence-specific learning[4, 20]. Although there was a significant main effect of EPOCH, the interaction between EPOCH and TRIPLET TYPE was not significant. This result implies that while general skill learning improved during rest, there was no change in sequence-specific learning. Furthermore, the lack of significant main effects or interactions for GROUP means that task B's interference had no effect on task A; that is, the integration of learning in task A occurred early in practice.

In Experiment 2, we inserted an interference task early in the practice where overlearning would not occur. However, an interference task did not affect sequence-specific learning performance in the retention phase. Consequently, the stabilization of the performance of sequence-specific learning was not due to overlearning, but to the integration at an early stage of practice. This result supported the view that the consolidation of sequence learning would occur early in practice[10, 25].

Therefore, implicit sequence-specific learning may facilitate early performance stabilization when a physical therapist trains a patient to learn a motor skill.

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