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Repetition of a cognitive task promotes motor learning

Takehide Kimura[a,*], Wataru Nakano[a,b]

[a] Department of Physical Therapy, Faculty of Health Sciences, Tsukuba International University, 6-8-33 Manabe, Tsuchiura, Ibaraki, Japan
[b] Department of Physical Therapy, Faculty of Health and Medical Sciences, Tokoha University, 1-30 Mizuochityou, Aoi-ku, Shizuoka, Shizuoka, Japan

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ABSTRACT

Motor learning plays an important role in the acquisition of new motor skills. In this study, we investigated whether repetition of a cognitive task promoted motor learning. Fifty-one young adults were assigned to either the early, late, or control groups. All participants completed a mouse tracking task in which they manipulated a mouse to track a moving target on a screen. The cursor was rotated 165° in the counterclockwise direction from the actual mouse position, requiring participants to learn how to use a new tool. To determine the task performance, we calculated the distance between the cursor and target position. In addition, to assess the effects of a cognitive task on the progress of motor learning, curve fitting of the learning curves was performed for the total distance. Experiments were conducted as per the following schedule: learning day 1 (L1), learning day 2 (L2: the day after learning day 1), retention day 1 (R1: 2 weeks after learning day 1), and retention day 2 (R2: 4 weeks after learning day 1). Participants underwent mouse tracking for 20 min on L1 and L2 and for 3 min on R1 and R2. As a cognitive task, we adopted the N-back task. The early or late group performed the N-back task for 20 min before performing motor tracking task on L1 or L2, respectively. The control group did not perform the N-back task. Based on curve fitting analysis, it was observed that the rate of change for motor learning in the early group was higher than that in the control group. The retention of motor learning did not differ between all groups. Our results indicate that the repetition of a cognitive task enhanced in the early phase of motor learning of the mouse tracking task.

1. Introduction

Motor learning plays an important role in the motor recovery in athletes or in patients following a stroke (Krakauer, 2006; Nielsen & Cohen, 2008). Repeated practice of a motor task often induces or reinforces motor learning (Dayan & Cohen, 2011; Wolpert, Diedrichsen, & Flanagan, 2011). However, repeated practice required a lot of time to establish the motor learning. Therefore, if motor learning induced by repeated practice was established more quickly, we could acquire the new motor skills earlier.

Recently, non-invasive neurostimulation techniques have focused attention as a method for the promotion of motor learning. Non-invasive neurostimulation techniques, such as transcranial direct current stimulation (tDCS), modulate an excitability of distinct brain regions. Previous tDCS studies revealed that motor learning is promoted by changed excitability in associated brain regions [i.e., primary motor cortex, premotor cortex or dorsolateral prefrontal cortex (DLPFC)] (for a review, see (Buch et al., 2017; Simonsmeier, Grabner, Hein, Krenz, & Schneider, 2018)). However, unfortunately, tDCS and the other non-invasive neurostimulation techniques are difficult to introduce in the clinical field due to the following factors: 1) they may cause adverse symptoms, such as a

* Corresponding author at: Department of Physical Therapy, Faculty of Health Sciences, Tsukuba International University, 6-8-33 Manabe, Tsuchiura, Ibaraki 300-0051, Japan.
E-mail address: t-kimura@tius.ac.jp (T. Kimura).

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headache (Poreisz, Boros, Antal, & Paulus, 2007), 2) the necessary equipment is costly, and 3) professional expertise is required to apply these techniques, which is not easily administered.

Motor imagery and cognitive tasks are widely employed, non-invasive neurostimulation techniques to bring about differential excitability in the brain, and to be easily introduced in the clinical field. Motor imagery enhanced the excitability of the primary motor cortex, premotor cortex, basal ganglia, and DLPFC (Hardwick, Caspers, Eickhoff, & Swinnen, 2018; Jeannerod, 2001). However, when participants have a less-developed brain network associated with motor skill, which is a target for motor imagery, a change in the brain excitability might not be obtained (Ahn & Jun, 2015). Therefore, prior to the learning of a new motor skill, or a new compensatory behavior, motor imagery-induced changes in brain excitability may be difficult to obtain. Acknowledging these results, in the present study, we investigated the possibility of the cognitive task as a method for promoting motor learning.

Neuroimaging studies have revealed that repetition of a specific cognitive task can change the excitability of distinct brain regions (Olesen, Westerberg, & Klingberg, 2004; Thompson, Waskom, & Gabrieli, 2016; Westerberg & Klingberg, 2007). In addition, this change in excitability may affect the performance of other tasks. For example, the enhancement of DLPFC excitability induced by tDCS improved dual-task performance (Zhou et al., 2014). Similarly, another study found that repetition of a cognitive task (i.e., N-back task) enhanced the excitability of the DLPFC and resulted in improvement of dual-task performance (Heinzel, Rimpel, Stelzel, & Rapp, 2017). Therefore, the repetition of a cognitive task may not only potentiate changes in brain excitability, but also influence the performances in other tasks.

The aim of the present study was to investigate whether repetition of a cognitive task promoted motor learning. To assess the change in the progress of motor learning, we measured the visuomotor adaptation skill using a mouse tracking task. The visuomotor adaptation skill was one of the elements constituting motor learning (Doyon & Benali, 2005; Seidler, 2006). For performing the mouse tracking task, the participants were required to modify their movements in response to a systematic alteration of visual inputs and were required to learn to use a novel tool. Additionally, the DLPFC, dorsal anterior cingulate cortex (ACC), and parietal regions were involved in the early phase of motor learning involving visuomotor adaptation (Anguera, Reuter-Lorenz, Willingham, & Seidler, 2010, 2011). As a cognitive task in the present study, we adopted the N-back task. The N-back task is considered to enhance the excitability of the DLPFC, premotor and other brain regions (Owen, McMillan, Laird, & Bullmore, 2005). Similar to promotional effect of tDCS on motor learning, we hypothesized the N-back task to enhance the brain excitability in response to visuomotor adaptation through motor learning, and that this enhancement may contribute in promoting motor learning required for the subsequent mouse tracking task.

To further parse our findings, we divided the motor learning period into two halves (early and late). The brain regions involved in motor learning of the visuomotor adaptation varied depending on the time course of motor learning (Anguera et al., 2010, 2011; Imamizu et al., 2000; Kim, Ogawa, Lv, Schweighofer, & Imamizu, 2015). Therefore, we hypothesized the N-back task to promote significant motor learning in the early phase, because of the overlap between the brain regions to be activated during motor learning and those involved in the N-back task in the early phase of motor learning.

2. Methods

2.1. Participants

Fifty-one healthy adults (19 female) were recruited. They were all right-handed, as assessed by the Edinburgh Inventory. Prior to the experiment, a neurological and musculoskeletal health questionnaire was given to each participant. No participants were excluded due to neurological and musculoskeletal disorders. Thereafter, all participants provided written informed consent according to the declaration of Helsinki prior to their study enrollment. All study protocols were approved by the Ethics Committee of Tsukuba International University (approval number: 29–30). Participants were randomly assigned to one of the following three groups: 1) early group ($n = 17$), 2) late group ($n = 17$), and 3) control group ($n = 17$).

2.2. Experimental environment

All experiments were conducted in a quiet room at Tsukuba International University. Participants were seated on a chair. A computer [Apple MacBook Pro: Retina, 13-inch, Early 2015 (flash rate: 60 Hz)] was placed on a desk in front of the participant. The computer display (resolution 2560 × 1600 pixels, refresh frequency 60 Hz, background luminance of 250 cd/m^2) was 60 cm from the participant's eyes, at a visual angle of 26.8° (width) and 17.0° (height). A computer mouse (M-IR07DR, ELECOM) was placed on the desk. The programs used in all experiments were written in Matlab R2017a (MathWorks, Natick, MA), using Matlab's Psychtoolbox (Brainard, 1997). During the experiment, the experimenters waited outside the experimental room, in which silence was maintained.

2.3. Evaluation of motor learning (Mouse tracking task)

A commonly-used mouse tracking task was employed here to investigate the progress of motor learning via manipulation of a novel tool (Imamizu et al., 2000; Ogawa & Imamizu, 2013). In this task, participants moved the computer mouse using the right hand. A target was displayed (red dot; 4 mm in diameter) along with a cursor (white dot; 4 mm in diameter) on a black background. After a starting message "GO" was shown for 2 s, the target and cursor were moved to the center of the display. Throughout the trial, the target position (X_{target}, Y_{target}) changed according to the following function: (X_{target}, Y_{target}) = (F_X (t) = 450 × cos (t + π/2), F_y (t) = 150 × sin (4 t)). The value of t increased by 1 every 1/60 s. Consequently, the target position moved linearly by about 5.3 cm

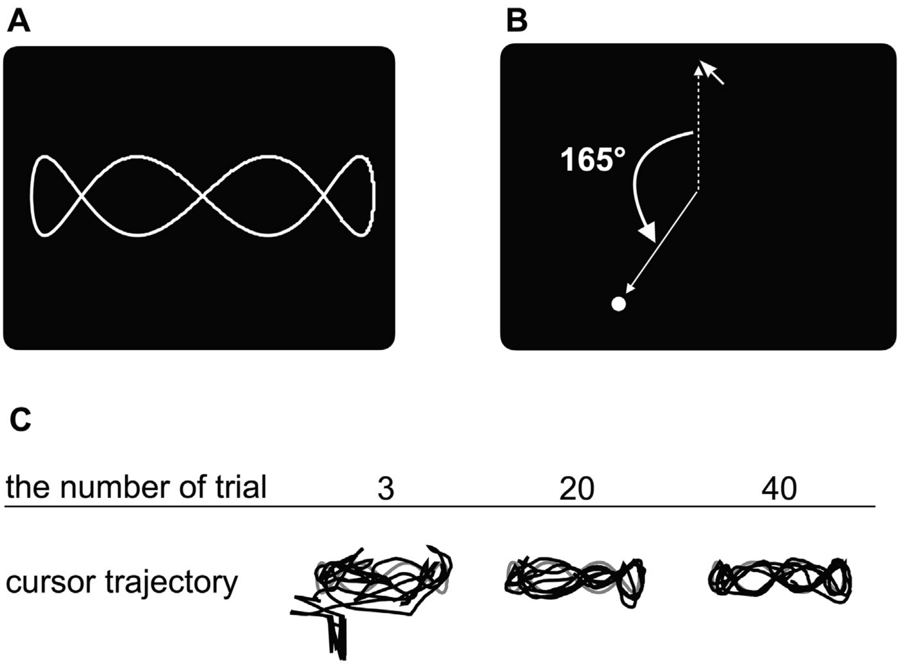

Fig. 1. (A) The trajectory of the target dot. (B) The relationship between the direction of mouse movement and the cursor. The direction of the cursor (white dot) was rotated 165° counter-clockwise from the direction of the mouse movement. (C) Example: Cursor trajectory for each trial. With repeated practice, deviations between the target and cursor were reduced.

per sec. The trajectory of the target is shown in Fig. 1A. Participants moved the cursor with the computer mouse and were instructed to track the target using the cursor during one trial for 60 s.

Two types of mouse tracking task were adopted in the present study. First, for the normal task, the movements of the cursor were not manipulated. This task was performed at the beginning of each experimental day to understand or confirm the procedure of the mouse tracking task. Second, in the rotation task, the movement of the cursor was manipulated. The cursor was rotated 165° counter-clockwise to the direction of mouse movement (Fig. 1B). The target and cursor positions were sampled at 60 Hz. Participants performed the mouse tracking task according to the following time schedule: learning day 1 (L1), learning day 2 (L2: the day after learning day 1), retention day 1 (R1: 2 weeks after learning day 1), and retention day 2 (R2: 4 weeks after learning day 1). On each day, participants underwent a practice session which consisted of one normal task and one rotation task. After that, on L1 and L2, participants completed 10 trials of the rotation task. After a one-minute break, participants then underwent 10 trials of the rotation task again. An example of change in cursor trajectory for each trial was shown in the Fig. 1C. On R1 and R2, participants underwent three trials of the rotation task. We repeatedly examined the number of trials per learning day in preliminary experiments such that task performance was allowed to plateau and motor learning was sufficiently established across the L1 and L2 learning days.

2.4. Cognitive task

We adopted the N-back task as a cognitive task for use in the present study. In the N-back task, sequences of 30 visual numeric stimuli (0–9) were presented at the center of a black computer screen for 0.5 s. A fixation point appeared on the screen between stimuli for 1 s. In the 1-back task, participants were instructed to press any key on the keyboard whenever the presented visual stimulus was identical to that shown immediately prior. In the 2-back task, participants were instructed to press any key on the keyboard whenever presented with a visual stimulus that was identical to that presented next to last (Fig. 2). In this way, participants responded by pressing any key with the right index finger whenever the current stimuli matched the target stimuli presented in the N back task. A total of 30 stimuli were presented in each block, 12 times of which required a response. Each training session comprised two runs, and each run consisted of six blocks. We allowed for a short 10-s rest period rest between blocks and a 120-s rest period after each run. In total, this cognitive task session was approximately 20-min long. The N number in the N-back task was set to 1 for the first block. When a participant successfully completed the block with a hit rate above 90% and a false alarm rate below 10%, we increased the N number by 1 in the next block. The results of hits and false alarms were immediately reported to the participants.

2.5. The timing of performing the N-back task in each group

Participants in the early group performed the N-back task session immediately before performing the mouse tracking task on L1. On the other hand, participants in the late group performed the N-back task session immediately before performing the mouse

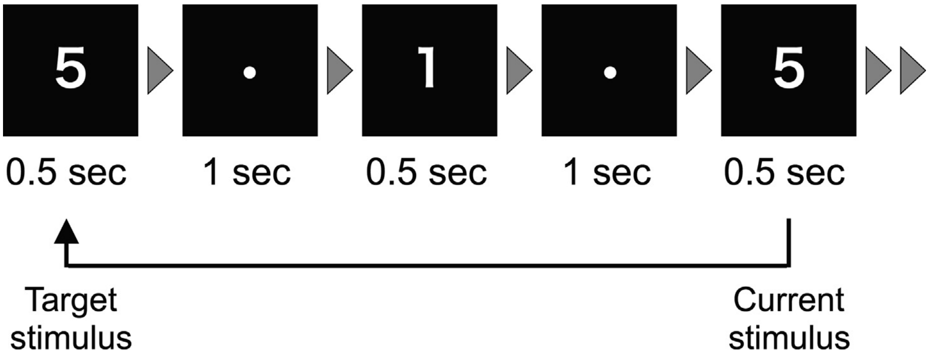

Fig. 2. Example of a 2-back task. Participants were instructed to press any key on the keyboard whenever they were presented with a visual stimulus that was identical to the one presented prior to the previous one.

tracking task on L2. In the control group, participants did not perform the N-back task.

2.6. Data analyses

In the mouse tracking task, we analyzed the positional data of the target (X_{target}, Y_{target}) and cursor (X_{cursor}, Y_{cursor}) offline. These data were filtered at 15 Hz with a low-pass Butterworth filter. Thereafter, we calculated the error distance (cm) between the target and cursor position at each time point. The formula used to calculate the error distance was as follows:

$$error\ distance = \sqrt{(X_{target} - X_{cursor})^2 + (Y_{target} - Y_{cursor})^2}$$

Finally, the total error distance (cm) was calculated by summing the error distance of each time point, and this distance was defined as the trial performance.

To assess the effects of a cognitive task on the progress of motor learning, curve fitting of the learning curves was performed using a single exponential, with 3 floating parameters (Newell, Mayer-Kress, Hong, & Liu, 2009; Singh, Jana, Ghosal, & Murthy, 2016) for the total error distance and number of trials of the rotation task on L1 and L2. The fitting equation obtained was of the form $f(x) = a + be^{(-cx)}$, where a Matlab Curve Fitting Toolbox (MathWorks) was utilized to calculate the averages and the statistical significances of the parameters (a, b, c) with a 95% confidence interval. The parameter x represents the trial number (i.e., 1–40), a is the asymptotic (steady-state) total error distance value, b is the amount of learning (the change in the total error distance due to training), and c is the steepness, indicating the rate of change for motor learning. The quality of the curve fitting was evaluated by the root mean square error (RMSE) and the coefficient of determination (r^2) values. To assess the cognitive task for the retention of motor learning, we averaged the results of the rotation task on R1 and R2 and defined this result as the task performance on R1 and R2.

Additionally, we calculated the phase difference between the target and cursor movement in the last trial on L2 to evaluate whether the participants correctly performed the "tracking task" through L1 and L2 (e.g., participants may predict the target's movement and move the cursor at their own pace). Initially, we divided the result of the cursor position data with the × (X_{cursor}) and y (Y_{cursor}) coordinate components, respectively. During the analysis of the x coordinate component, we fitted the X_{cursor} curve to the following equation, with 1 floating parameters; $f(t) = 450 \times \cos(t + \pi/2 + d_1)$, where the parameter t represents the time scale, and the parameter d_1 indicates the phase difference (radian) as a difference of the x coordinate component between X_{target} and X_{cursor}. During the analysis of the y coordinate component, we fitted Y_{cursor} curve to the following equation, with 1 floating parameters; $f(t) = 150 \times \sin(4t + d_2)$, where the parameter d_2 indicates the phase difference (radian) as a difference of the x coordinate component between Y_{target} and Y_{cursor}. The Matlab Curve Fitting Toolbox (MathWorks) calculated the averages and statistical significances at 95% confidence interval, of parameters d_1 and d_2. A negative value of the d_1 or d_2 parameter indicates the late movement of the cursor to the target.

N-back task performance was defined as the N number in the last block.

2.7. Statistical analyses

All statistical analyses were conducted using SPSS version 25 (IBM, Corp, Armonk, NY). All data were checked for normality in their distribution, and equal variance using the Shapiro-Wilk test. The inter-group differences among the baseline characteristics were evaluated using a one-way repeated analysis of variance (ANOVA) or a chi squared test, with groups (early, late or control) as the variable. We applied a one-way repeated ANOVA on the results of curve fitting parameters (a, b, and c), and the result of phase difference analysis (d_1 and d_2) with group as the variable. Additionally, to assess the quality of the curve fitting, we applied a one-way repeated ANOVA for RMSE and r^2 with group as the variable. The retention of motor learning was analyzed using a two-factor mixed-design repeated ANOVA, with group as the inter-group variable and time (on R1 or R2) as the intra-group variable. Bonferroni's post-hoc tests were also conducted. To compare the result of the N-back task performance between the early and late groups, the Wilcoxon singed-rank test was used. The differences were considered statistically significant when $P < 0.05$. The effect size for each statistical test was calculated as eta squared (η^2) or r.

Table 1
Characteristics of participants in each group.

	Early group (n = 17)	Late group (n = 17)	Control group (n = 16)	p value
Age (years)[a]	20.5 ± 1.5	20.8 ± 0.8	20.4 ± 1.4	0.627
Gender (male/female)[b]	11/6	9/8	11/5	1.000
Task performance at the start of the mouse tracking task (cm)[a]	19431.3 ± 9081.6	21013.1 ± 4264.8	20241.2 ± 4659.1	0.774

p value, inter-group difference.
[a] Values are mean ± SD.
[b] Values are frequency.

3. Results

The data of one participant from the control group was excluded from the analysis due to high variability in the mouse tracking task performance, because of its inadequate fit to the curve fitting model ($r^2 < 0.40$). This exclusion was applied on the basis of previously described exclusion criteria (Joseph, King, & Newell, 2013). Thus, the total number of participants in the control group reduced to 16. No significant differences between the groups were observed for the baseline characteristics (Table 1).

3.1. Changes in mouse tracking task performance

The results of the mouse tracking task throughout the experiment, in all groups, are shown in Figs. 3 and 4. Additionally, the results of curve fitting for each group are shown in Fig. 4 and Table 2. The asymptotic total error distance value (parameter a) and the amount of learning (parameter b) did not differ between the groups (parameter a: $F_{2, 49} = 0.249$, $p = 0.781$, $\eta^2 = 0.010$; parameter b: $F_{2, 49} = 1.036$, $p = 0.363$, $\eta^2 = 0.042$). On the other hand, the rate of change for learning (parameter c) differed significantly between the groups ($F_{2, 49} = 3.734$, $p = 0.031$, $\eta^2 = 0.138$). Post hoc tests revealed that the value of the rate of change of learning in the early group was significantly higher than in the control group ($p = 0.032$). The RMSE and r^2 did not differ between groups (RMSE: $F_{2, 49} = 2.161$, $p = 0.126$, $\eta^2 = 0.084$; r^2: $F_{2, 49} = 2.087$, $p = 0.135$, $\eta^2 = 0.080$).

In the retention of motor learning, there was no significance in the two-way interactions and main effects (two-way interaction (Time × Group): $F_{2, 47} = 0.374$, $p = 0.690$, $\eta^2 = 0.016$; main effect of Time: $F_{1, 47} = 0.046$, $p = 0.832$, $\eta^2 = 0.001$; main effect of Group: $F_{2, 47} = 1.941$, $p = 0.155$, $\eta^2 = 0.076$). The results of the mouse tracking task performance on R1 and R2 for each group are shown in Table 3.

In the analysis of phase differences, the parameters d_1 and d_2 did not differ between the groups (d_1: $F_{2, 49} = 0.275$, $p = 0.761$, $\eta^2 = 0.013$; d_2: $F_{2, 49} = 0.901$, $p = 0.413$, $\eta^2 = 0.037$). The RMSE and r^2 values from the phase difference analysis did not differ between groups in the x-axis analysis (RMSE: $F_{2, 49} = 1.026$, $p = 0.366$, $\eta^2 = 0.042$; for r^2: $F_{2, 49} = 0.749$, $p = 0.478$, $\eta^2 = 0.027$), and in the y-axis analysis (RMSE: $F_{2, 49} = 1.583$, $p = 0.216$, $\eta^2 = 0.063$; for r^2: $F_{2, 49} = 0.861$, $p = 0.429$, $\eta^2 = 0.035$). The results of each parameter in all the groups are shown in Table 4.

3.2. Cognitive task performance results

At the end of the cognitive task session, the mean N number of the N-back task was 3.64 ± 1.54 in the early group and

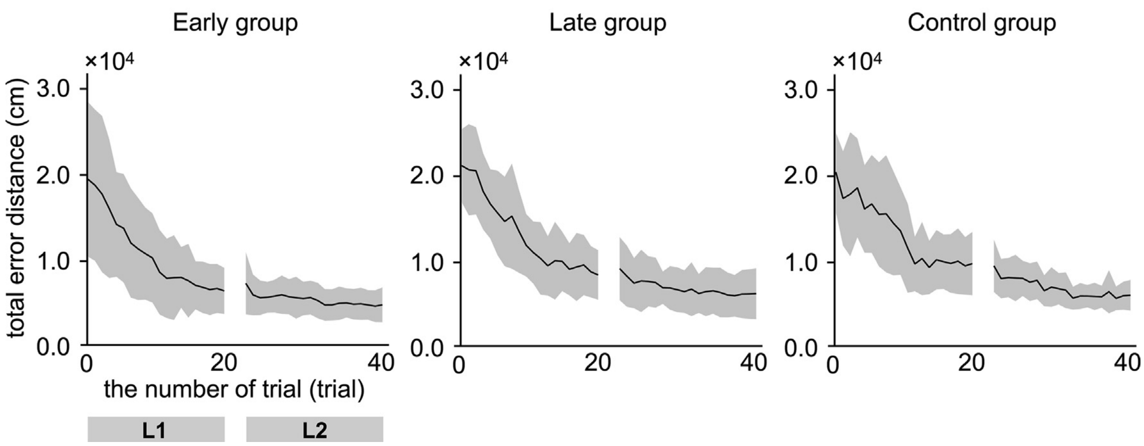

Fig. 3. Change in the mean (± SD in shaded region) mouse tracking task performance in each group. Abbreviations: L1, learning day 1; L2, learning day 2.

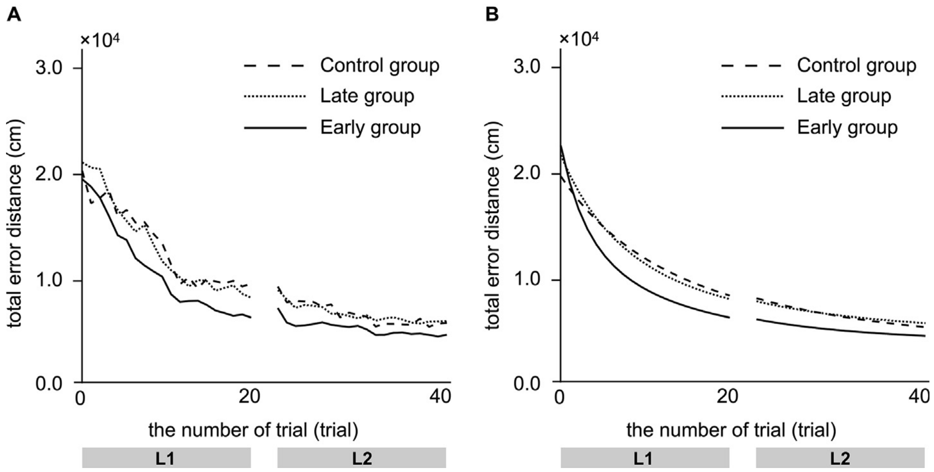

Fig. 4. (A) Changes in the mean mouse tracking task performance in all groups. (B) The result of curve fitting analysis in all groups. Abbreviations: L1, learning day 1; L2, learning day 2.

Table 2
The result of curve fitting analysis in each group.

	Early group	Late group	Control group
Asymptotic total error distance (cm)	3937.8 ± 2459.1	4490.1 ± 4066.1	3722.7 ± 2963.2
Amount of learning (cm)	23564.9 ± 12731.7	19367.7 ± 6242.8	17334.2 ± 7907.7
Rate of change for learning	0.18 ± 0.14*	0.12 ± 0.07	0.09 ± 0.05
r^2	0.91 ± 0.07	0.89 ± 0.08	0.85 ± 0.11
RMSE (cm)	1272.4 ± 603.1	1476.3 ± 525.0	1702.8 ± 651.8

Abbreviation: RMSE, Root Mean Square Error. Values are mean ± SD. *Significant difference compared with Control group, at $p < 0.05$.

Table 3
The result of mouse tracking task performance on Retention day 1 (R1) and Retention day 2 (R2) in each group.

	Early group	Late group	Control group
The result of task performance on R1 (cm)	4398.1 ± 1665.6	5794.4 ± 2803.2	5135.6 ± 1520.1
The result of task performance on R2 (cm)	4439.3 ± 1788.5	5540.9 ± 2144.7	5233.6 ± 1511.0

Values are mean ± SD.

Table 4
The result of phase difference analysis in each group.

	Early group	Late group	Control group
1. Analysis for × coordinate component			
Phase difference (radian)	−0.07 ± 0.05	−0.04 ± 0.13	−0.04 ± 0.10
r^2	0.97 ± 0.03	0.96 ± 0.06	0.95 ± 0.05
RMSE (radian)	1.12 ± 0.55	1.24 ± 0.61	1.42 ± 0.62
2. Analysis for y coordinate component			
Phase difference (radian)	−0.25 ± 0.18	−0.29 ± 0.33	−0.17 ± 0.21
r^2	0.75 ± 0.18	0.68 ± 0.22	0.66 ± 0.24
RMSE (radian)	1.22 ± 0.50	1.37 ± 0.50	1.55 ± 0.61

Abbreviation: RMSE, Root Mean Square Error. Values are mean ± SD.

3.94 ± 1.43 in the late group, with no significant difference between them ($Z = 0.896$, $p = 0.370$, $r = 0.154$).

4. Discussion

In the present study, we investigated whether repetition of a cognitive task promoted motor learning. The analysis of phase difference suggested that the participants in each group moved the cursor in response to the movement of the target and performed the mouse tracking task correctly. From the curve fitting analysis, the rate of change for motor learning (i.e., steepness of fitting curve) was higher in the early group than in the control group. This result indicated that the repetition of a cognitive task promoted motor learning in the early motor learning phase. To the best of our knowledge, this is the first study to demonstrate repetition of a cognitive task contribute to promoting motor learning.

Previous studies using tDCS suggested that changes in the brain excitability may influence the motor learning (Buch et al., 2017; Simonsmeier et al., 2018). In the present study, the N-back task was considered to enhance the DLPFC, premotor cortex, dorsal cingulate cortex, and other brain regions (Owen et al., 2005). On the contrary, during the mouse tracking task, we hypothesized the involvement of various brain regions because the task comprised at least two components: 1) The visuomotor adaptation task component and 2) The tracking component. That is, the participants required adaptation in operating the mouse using visual feedback, and to track the target. Neuroimaging studies of participants performing the visuomotor adaptation task showed that the right DLPFC, dorsal ACC, and parietal regions were involved in the early phase of motor learning (Anguera et al., 2010, 2011). In the late phase, however, the cerebellar and parietal regions were involved (Imamizu et al., 2000; Kim et al., 2015). On the contrary, the tracking task involved the precentral gyrus, middle occipital gyrus, putamen, cerebellum, and other brain regions, although it was unknown whether the brain excitability changes depending on the phase of motor learning (Wadden, Brown, Maletsky, & Boyd, 2013). Our results indicated that the N-back task promoted motor learning in the early phase. Therefore, we speculated that a congruence between the brain regions involved in motor learning and enhancing the neural excitability, as indicated by the N-back task, was an important factor for promoting motor learning. The primary activation of the brain regions involved in motor learning may eventually lead to the subsequent promotion of future motor learning behaviors. On the contrary, in the late phase of motor learning, the lack of promotion of motor learning may be due to the absence of the hypothesized congruence of the brain regions.

The anodal tDCS enhanced, while the cathodal tDCS reduced the brain excitability (Nitsche & Paulus, 2000). To the best of our knowledge, many studies have reported that an anodal tDCS over the primary motor cortex promoted motor learning, but the anodal tDCS over other brain regions (e.g., the DLPFC or premotor) did not influence motor learning (Buch et al., 2017; Simonsmeier et al., 2018). For example, Nitsche et al. revealed that an anodal tDCS over the primary motor cortex promoted motor learning of serial reaction time task (Nitsche et al., 2003); However, no such activity was observed following stimulation of the premotor cortex and DLPFC. Kantak et al. reported that anodal tDCS over the primary motor cortex promoted the motor learning of serial reaction time task, but not be promoted by anodal tDCS over the premotor cortex (Kantak, Mummidisetty, & Stinear, 2012). On the other hand, Zhu et al. reported the cathodal tDCS over the DLPFC promoted the motor learning in a golf patting task (Zhu et al., 2015). Primarily, our results seem to contradict the reported tDCS studies. This divergence in findings may be due to the following factors: 1) The task used for evaluating motor learning in the present study differs from that used previously elsewhere and 2) The N-back task may activate multiple brain regions and/or networks (Owen et al., 2005) including regions other than the DLPFC or premotor cortex, and this enhancement of a wide range of brain excitability may contribute to the promotion of motor learning. Because we did not measure the brain activity, the precise nature and cause of these differences are yet to be elucidated. Further study was needed to investigate the relationship between the changes in brain excitability induced by the N-back task and the promotion of motor learning.

Another possibility for the promotion of motor learning in the early group is a difference in room for improvement of task performance between on L1 and L2. The mouse tracking task performance was much improved on L1 compared with L2. Because there was more room for improvement of task performance on L1, N-back task performance effects might be more readily observed on L1.

The retention of motor learning did not differ between all the groups (not observed the main effect of the groups) and between the groups on R1 and R2 (not observed the main effect of time). Because the mouse tracking task performance on R2 did not impair as compared on R1, we hypothesized that the interval between the end of the learning day and the retention day to be short and it might be difficult to evaluate the retention of motor learning in the present study. A longer interval between the end of the learning day and the retention day may aid in the evaluation of the effect of cognitive task on the retention of motor learning more efficiently. Therefore, further study with a particular emphasis on this resting interval is needed and can be achieved by adjusting the experimental protocols.

As opposed to tDCS, the cognitive tasks can be performed without the requirement of professional expertise or use of expensive equipment. Based on these advantages, cognitive tasks can easily be added to the conventional training paradigms and methods. On the other hand, the repetitive performance of cognitive tasks may induce mental fatigue. Mental fatigue might cause several adverse events including fall and reduction of endurance and performance (Grobe et al., 2017; Van Cutsem et al., 2017). Therefore, the occurrence of several accidents due to mental fatigue was particularly noted.

4.1. Limitations

The present study had several limitations. First, we did not measure the change in neural/cortical excitability induced by N-back task. Therefore, we could not identify a mechanism through which cognitive task promoted motor learning. Second, it was unknown whether the same result of the present study could be obtained by the other motor task. Further study is need to reveal whether cognitive task promote the motor learning of other motor task such a gross motor task and movement related to rehabilitation. Third, the mouse tracking task consisted of at least two components and was complicated by nature. Our results could not identify the component more influenced by the N-back task. It may, therefore, be advisable to use a simpler motor task to clarify a particular characteristic which may significantly impact the effect of the cognitive task.

5. Conclusions

The repetition of a cognitive task promoted motor learning in the early phase. We show that cognitive tasks have the potential for a progress-dependent promotion of motor learning.

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Declarations of interest

The authors declare that they have no conflict of interest.

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