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The effects of short-term practice on executive functions

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Executive functions (EFs) are considered to be functions that adaptively control actions and thoughts in daily life, and consist of three components—updating, shifting, and goal-related processing. Previous studies reported that EF task performance is improved after practice over 1 month. Actually, improvement is often observed to begin earlier. Thus, we hypothesized that practice effects would occur even after short-term practice of approximately 30 minutes for each EF. In the present study, we measured the practice effect of EFs as a function of the number of blocks by using three behavioral tasks corresponding to the three components (Miyake et al., 2000). The results revealed that although the practice effect for the goal-related processing component task was marginally significant, even short-term practice of the updating and shifting components significantly improved performance. The findings suggest that an efficient practice schedule for EFs might exist, which can be linked to a possible resolution of psychological adjustment problems that individuals with EF deficits and maladaptive behavior have in daily life.

Key words: executive functions, practice effects, short-term practice

Introduction

General intelligence is conventionally known to be essential for humans to behave adaptively in various environments (e.g., Sternberg, 1994). However, recently, executive functions (EFs) are drawing attention in such adaptive daily life behaviors as planning, decision making, and controlling actions (Damasio, 1994; Friedman et al., 2006). EFs are defined as functions that control actions and thoughts (Baddeley & Hitch, 1974; Miyake et al., 2000). Though EFs may share similar roles with general intelligence, previous studies demonstrate that they are different. Some individuals with frontal lobe damage show EF deficits directly related to maladaptive behavior, but have intact general intelligence as measured by traditional intelligence tests (Damasio, 1994; Miyake et al., 2000). Thus, EFs are considered to be different from general intelligence and to be critical functions for adaptive social life.

Recent empirical studies reported that EFs are constructed from three functional components: updating, shifting, and goal-related processing (Miyake et al., 2000; Friedman et al., 2008; Friedman & Miyake, 2017). Updating is the ability to update and eliminate information content included in working memory. Shifting is the ability to flexibly switch

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mental sets. Goal-related processing is the ability to maintain and manage goals, and use those goals to adjust ongoing processing. The goal-related processing component is also referred as "Common-EF" by Friedman and Miyake (2017) and had a modulatory effect on all the EF tasks used by Friedman et al. (2008).

An important related issue is the improvement of EFs after practice (Dahlin, 2009; Klingberg, 2010), because the effects of practice may be a measure of improved ability for individuals with EF deficits to adapt to their environment. The present study examined the effect of short-term practice on EFs. Most previous studies demonstrated that performance in EF tasks is significantly affected by practice for more than one month (Basso, Bornstein, & Lang, 1999; Benikos, Johnstone, & Roodenrys, 2013; Verbeken, Braet, Goossens, & Oord, 2013). It remains to be determined whether there is a possible limit to how long practice affects performance on EF tasks corresponding to all three components. Collie, Maruff, Darby, and McStephen (2003) showed improvement of performance on various tasks during the early phase of practice. Therefore, we hypothesized that practice effects would occur even in short-term practice of approximately 30 minutes for each EF task. We predicted that performance on EF tasks would improve (i.e., accuracy rate becomes higher and response time becomes shorter) as each trial for each EF task was repeated.

Method

Participants

Twenty-four healthy graduate and undergraduate students (age of 21.38 years, SD = ±1.96 years) participated in this study. All experiments were approved by the Ethical Committee of Tohoku Fukushi University and conducted according to principles of the Declaration of Helsinki. Written informed consent was obtained from all participants.

Materials, EF Tasks, and Procedure

All stimuli were made using MATLAB (The MathWorks, Inc., Natick, MA) and the Cogent Graphics package (http://www.vislab.ucl.ac.uk/cogent.php). Stimuli were controlled on a PC (Epson Endeavor MT7900, Epson, Nagano, Japan) and were presented on a CRT monitor (Mitsubishi Diamondtron Flat RDF225; resolution 1024 × 768 pixels; refresh rate 60 Hz, Mitsubishi, Tokyo, Japan). In the present study, three of the nine EF tasks used in Friedman et al. (2008)'s study were used; each of these corresponds to one of the three functional components. Completion of all tasks takes approximately two hours, including 10-minute rests after the completion of each task. The number of blocks for each task was decided so that each task could be completed within approximately 20-30 minutes, considering the experimental load imposed on participants. The order of tasks was counterbalanced for every participant.

Updating task: Keep track task. Figure 1 shows the stimulus sequence of the keep track task. Participants firstly were presented two, three, or four target categories of six possible categories（動物, 色, 国, 時, 金属, 家族）at the bottom of the display. Fifteen words, including two or three words from each category, were serially presented at the center of the display in random order after participants pressed the space key. Each word was presented for 1500 milliseconds (ms). After the stimulus presentation, they wrote down the last presented word in each of the target categories on the answer sheet. When they finished answering, they pressed the space key to perform the next trial. The task was performed in a practice block of three trials and four blocks of 12 trials. In the practice block, they performed three trials in order from two to four target categories, and then performed four times for each of two to four target categories in random order in each block. Participants were asked to recall a total of 36 words. The dependent measure was the proportion of words recalled correctly on each trial.

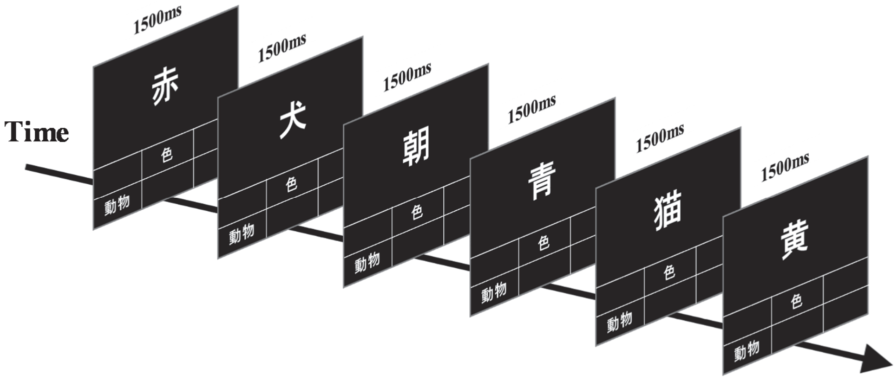

Figure 1. The stimulus sequence of the keep track task. The sequence shows the 2-category condition. In this case, the correct answers were “黄” for the “色” category and “猫” for the “動物” category.

Shifting task: Category switch task. Figure 2 shows the stimulus sequence of the category switch task. Participants were asked to categorize words at the center of the display as quickly and correctly as possible, depending on a cue in the upper part of the display in each trial. A word was randomly selected from words used by Mayr and Kliegl (2000) and translated into Japanese. A cue was a heart or a cross, which cued categorization in terms of whether the word described a living or nonliving thing, or whether it described a thing that is smaller or larger than a soccer ball. A word was presented 1500 ms after the onset of a cue. The word disappeared after they responded, and the next cue was presented after a blank of 350 ms. If participants did not respond during 1500 ms, the next trial was performed. A cue was randomly presented trial by trial with the constraint that no more than four switch trials could be performed. The right key was assigned to a living thing and a thing that is larger than a soccer ball, and the left arrow key to a nonliving thing and a thing that is smaller than a soccer ball. In the practice block, 24 trials were performed, including 12 switch trials and 12 no switch trials. In the test block, eight blocks of 54 trials were performed, including 27 switch trials and 27 no switch trials. The first six trials of each block were regarded as practice trials and excluded from the statistical analysis. The dependent measure was the switch cost, which is the median response time difference between the switch trials and no-switch trials.

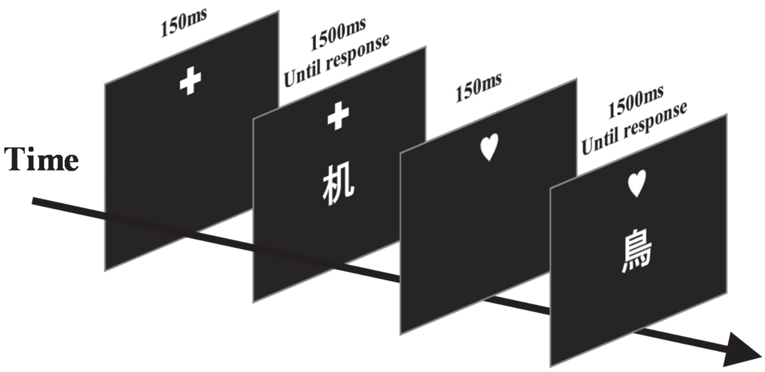

Figure 2. The stimulus sequence of the category switch task.

Goal-related processing task: Stop-signal task. Figure 3 shows the stimulus sequence of the stop-signal task. A square or a circle was randomly presented as the go signal at the center of the display for 1500 ms, following this a fixation cross was presented for 250 ms. The stop-signal (200 ms, 1800 Hz tone) was presented through headphones (DR-531, Elega Acous Co., Ltd., Tokyo, Japan) at a comfortable listening level. Participants were asked to judge a square or a circle as quickly and correctly as possible in the no-stop signal trial, and inhibit a response in the stop-signal trial. The stop-signal delay (SSD) was defined as the interval between the onset of the stop-signal and the go signal. The initial SSD was 250 ms; SSD was adjusted depending on participants' performance (Logan, Schachar, & Tannock, 1997). If a participant successfully inhibited (or failed to inhibit) a response on the stop-signal trial, then SSD increased (or decreased) by 50 ms. Participants were instructed to stop a response if they could when they heard the stop signal, but not to worry about failing to stop. They were also instructed that they should not wait for the stop-signal. There were eight practice trials, and six blocks of 72 trials were performed. In all blocks, stop-signals were presented on 25% of the trials in random order. The dependent measure was the median RT in the no-stop signal trials with correct response (go RT).

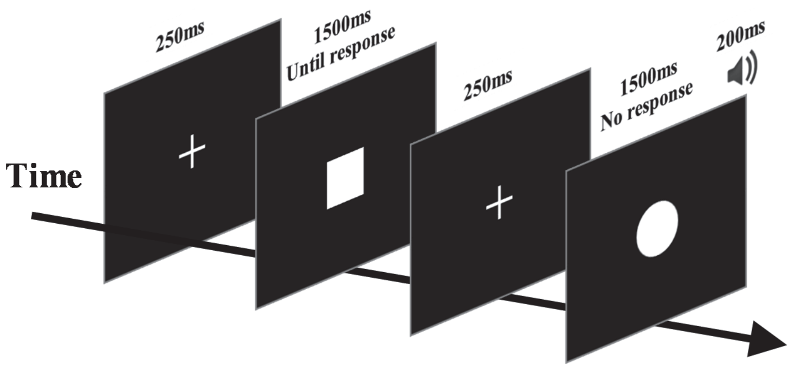

Figure 3. The stimulus sequence of the stop-signal task.

Results

Table 1 shows the mean accuracy (%) in the keep track task, the mean switch cost in the category switch task, and the mean median go RT in the stop-signal task across all participants as a function of the number of blocks. Repeated measures analysis of variance (ANOVA) for each dependent variable of each task was conducted on the variable of the number of blocks (and the number of target categories only in the keep track task).

In the keep track task, the main effects of both the number of target categories and the number of blocks were significant, $F(2, 46) = 72.24$, $p < .001$; $F(3, 69) = 8.30$, $p < .001$, respectively. The interaction was also significant, $F(6, 138) = 3.85$, $p = .001$. In the 3-target-categories condition, the simple main effect of the number of blocks was significant, $F(3, 207) = 3.21$, $p < .05$. In the 4-target-categories condition, the simple main effect of the number of blocks was significant, $F(3, 207) = 12.59$, $p < .001$. As the number of blocks increased, the proportion of correct recall became higher in the 3- and 4-target-categories condition. In the 2-target-categories condition, the proportion of correct recall was almost 100 % over all the blocks and there was no room for improvement in task performance.

In the category switch task, the main effect of the number of blocks was significant, $F(7, 161) = 3.90$, $p < .001$. As the number of blocks increased, the cost to switch categorization, the switch cost, became smaller.

In the stop-signal task, the data of one participant were excluded from the following analysis as an outlier for the percentage change score between the 1st and last blocks. The main effects of the number of blocks were marginally significant, $F(5, 100) = 2.20$, $p = .061$. As the number of blocks increased, the median go RT tended to become shorter.

Table 1. Descriptive and *F* statistics for the EF tasks. All data are presented as mean (±SD). Note: M = Mean; SD = Standard Deviation; ctgry (2) = 2-target category; ctgry (3) = 3-target category; ctgry (4) = 4-target category; RT = response time. %change was calculated by dividing the difference in values of the first and the last blocks by the value of the first block.
+p<.1; *p<.05; **p<.005; ***p<.001

EF tasks	Block 1 M (SD)	Block 2 M (SD)	Block 3 M (SD)	Block 4 M (SD)	Block 5 M (SD)	Block 6 M (SD)	Block 7 M (SD)	Block 8 M (SD)	%change	F statistic
Keep track task										
ctgry(2) accuracy (%)	98.44 (4.22)	96.35 (6.88)	98.96 (3.53)	96.88 (5.53)	-	-	-	-	-1.59	0.59
ctgry(3) accuracy (%)	90.28 (9.73)	93.4 (8.14)	95.49 (7.36)	96.88 (5.92)	-	-	-	-	7.31	3.21*
ctgry(4) accuracy (%)	73.7 (16.06)	79.43 (14.21)	83.33 (10.69)	86.98 (10.08)	-	-	-	-	18.02	12.59***
Category switch task										
switch cost (ms)	230.5 (163.82)	197.48 (148.38)	163.29 (122.63)	134.21 (110.54)	124.18 (114.63)	140.75 (151.96)	110.96 (138.89)	98.42 (86.34)	57.3	3.91***
Stop-signal task										
go RT (ms)	523.34 (112.25)	516.22 (137.42)	507.42 (94.02)	499.9 (81.58)	499.56 (89.64)	497.89 (99.02)	-	-	4.86	2.2+

Discussion

The results of this study indicated that the performance of EFs improved. Although the improvement by practice of the goal-related processing component was trending toward significance, generally improved performance of the updating and shifting components was obtained by short-term practice of approximately 30 minutes for each task.

The long-term practice effects were examined for the updating (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008) and shifting components (Basso et al., 1999). For the updating component, Dahlin et al. (2008) reported approximately 16 % performance improvement by long-term practice over five weeks. The present short-term practice produced improvement of 18.02 % for the updating component. Thus, both long- and short-term practice may have similar effects on the updating component. For the shifting component, Basso et al. (1999) reported that shifting performance improved 40.56 % (i.e., the number of perseverative errors decreased) by practice over 12 months. Even by very short-term practice in the present study, shifting performance displayed more improvement (57.3%) than in the previous study. Although it may be difficult to compare with different task performances for the percentage change scores (3-back task for Dahlin et al., 2008, and Wisconsin Card Sorting Test for Basso et al., 1999), it is possible that the maximal practice effect can be obtained with shorter practice time than previous studies indicated.

In this study, we did not examine transfer effects after short-term practice in other untrained EF tasks. Dahlin et al. (2008) reported transfer effects of updating practice (letter memory) over five weeks on the performance of the other updating task (n-back test). Considering that short- and long-term practice are suggested to have similar effects on the improvement of performance depending on the type of EF components involved, it is possible for the short-term practice effect to transfer to other untrained EF tasks. The findings of the present short-term practice effect and of possible transfer effects in future research could lead to efficient resolution of problems that individuals with EF deficits and maladaptive behavior have in daily life.

Acknowledgments

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