Comparison of Random and Blocked Practice during Performance of the Stop Signal Task

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Purpose: We investigated the changes in the stop-signal reaction time (SSRT) and the no-signal reaction time (NSRT) following motor sequential learning in the stop-signal task (SST). This study also determined which of the reductionos of spatial processing time was better between blocked- and random-SST.

Methods: Thirty right-handed healthy subjects without a history of neurological dysfunction were recruited. In all subjects, both the SSRT and the NSRT were measured for the SST. Tasks were classified into two categories based on the stop-signal patterns, the blocked-SST practice group and random-SST practice group. All subjects gave written informed consent.

Results: In the blocked-SST group, both the SSRT and the NSRT was significantly decreased ($p<0.05$) but not significantly changed in the random-SST group. In the SSRT and the NSRT, the blocked-SST group was faster than the random-SST group ($p<0.05$). In the post-test SST after practice of each group, the SSRT was significantly decreased in the random-SST group ($p<0.05$), but the NSRT showed no significant changes in either group.

Conclusion: These findings demonstrate that random-SST practice resulted in a decrease in internal processing times needed for a rapid stop to visual signals, indicating motor skill learning is acquired through improved response selection and inhibition.

Keywords: Stop function, Stop signal task, Motor sequential learning

I. Introduction

Stop function is a notable feature of executive control in response to changes in internal states or changes in the environment. This ability to stop inappropriate or irrelevant responses supports flexible and goal-directed behavior in every changing environment.[1,2] The deficits in stop function should be one of the key features of some neurological and psychopathological disorders such as Parkinson's disease, Huntington's disease, attention-deficit/hyperactivity disorder, and compulsive disorder.[3-7] Many previous studies have typically investigated the process of stop function using the stop signal paradigm, which was directly related to self-regulation of goal-directed behavior.[8-10]

The stop signal task (SST) is based on the race model of the stop signal paradigm.[11-13] Subjects perform the ongoing process, and occasionally, the ongoingprocess is followed by a stop-signal, which instructs subjects to stop the response (the stop process). Stopping a response requires a fast control mechanism that prevents the execution of the motor response. These processes interact with slower control mechanisms that monitor and adjust performance. Under the assumption of a race between ongoing and stopping processes, the stop-signal reaction time (SSRT) measures the time it takes for subjects to stop their response. The SSRT has proven to be an important measure of the executive control processes that are involved in stopping. Thus, successful performance in the SST involves monitoring the ongoing and stopping performance and adjusting response strategies to find an optimal balance between conflicting demands of the go- and stop-task.

Many previous studies have reported that subjects change

response strategies reactively after stop-signal trials.[14-16] Several studies indicated that subjects change response strategies proactively when they expect stop-signals to occur, trading speed in the go-task for success in the stop task.[17,18] Recent studies shown that stimulus repetition might be a crucial variable responding after successful stopping is typically slower when the stimulus from the stop trial is repeated, and retrieval of that association impaired go performance.[19] This stimulus-specific slowing can persist over many intervening trials and might support the development of automatic stop function.[20,21] According to functional MRI, cortical excitability and the involved regional area are altered after performance of the SST. Many studies have reported that successful stopping is associated with higher cortical function in the inferior frontal cortex (IFC) and dorsal medial frontal regions, especially the pre-supplementary motor area (pre-SMA) in voluntary stop.[11,15,22] The activation of these cortical regions through motor sequential learning of the SST can improve error detection and lessen conflict between responses and action plans, which are associated with monitoring and adjusting behavior. However, although the evidence for neural contribution to motor learning of ongoing performance such as the serial reaction time task is well established,[23,24] nothing has been presented the contribution to motor learning in resolving the conflict between the opposing task demands in the SST. Moreover, studies in human normal stop function would likely help us in understanding the automaticity process in motor sequence learning.

Therefore, we tried to demonstrate whether or not a blocked or random stop-signal pattern led to a change between the stop-signal reaction time and the no-signal reaction timefollowing motor sequential learning, as the final temporal response time was reduced after motor acquisition in the SST.

II. Methods

1. Subjects

Thirty healthy subjects were recruited using the following inclusion criteria: (1) right-handed as verified by a handedness questionnaire in the modified Edinburgh Handedness Inventory, (2) no pathology of musculoskeletal function in the upper limb, (3) no previous history of neurological or psychiatric disorders, (4) no previous exposure to other sequence-learning studies. All subjects were randomly assigned to a Blocked-SST practice group or a Random-SST practice group. All subjects gave their written informed consent prior to this experiment, which was in accordance with ethical standards of the Declaration of Helsinki.

2. Equipment and procedures

1) Stop Signal Task (SST)

The stop signal task (SST) was performed on the computer using stimulus presentation software (STOP-IT, Universiteit Gent, Belgium) and consisted of Go (75% of all trials) and Stop (25%) trials.[25,26] During the Go trial, visual stimuli with no colors, such as the square (■), circle (●), diamond (◆), or triangle (▲) was randomly displayed on a monitor to a subject, who was instructed to then press a response key consisting of a left (←), right (→), up (↑), or down (↑) arrow on the keyboard. During the Stop trial, a stop-signal (X shape) was presented following a particular delay (stop-signal delay, SSD), subsequently overlapping the figure signal. The SSD was initially set at 250 ms and continually adjusted according to a tracking procedure to obtain a probability of stopping of 0.50. If the subject successfully stopped the button press during a stop trial, the next stop trial became more difficult by increasing the SSD by 50 ms. If the subject failed to stop the button press, the next stop trial was made easier by decreasing the SSD by 50 ms.

The program ANALYZE-IT (Universiteit Gent, Belgium) was used for statistical analysis. Stop-signal reaction time (SSRT) and no-signal reaction time (NSRT) were estimated by calculating the mean SSD, the mean percentage of correct responses on the Go trials, and the probability of responding on the Stop trials according the stop signal paradigm.[25]

2) Experimental procedure

All subjects were seated in front of a table with the right hand on the response key. Subjects of each group performed the predictableor random SST, which consisted of the previously mentioned five figures (■, ●, ▲, ◆ and X) presented randomly on the center of a computer monitor. In the Blocked-SST, a Stop-signal was presented as every fourth signal within the Go trial, whereas a Stop-signal was randomly presented in the Random-SST. The SST was to respond to each stimulus with a predetermined set of response keys: the square meant that the subject had to press the "←" button; the circle

indicated the "→" button; the diamond indicated the "↑" button; and the triangle indicated the "↓" button.

In Go trials, the subjects were instructed to press the button as quickly as possible, but the subjects were not instructed to press the button during the Stop trials. The SST consisted of three blocks of 96 trials (Go trials: 72, Stop trials: 24) per session one of the three-time practice, whereas the SST consisted of one block of 128 trials (Go trials: 96, Stop trials: 32)in the test session. A fixation cross was shown on themonitor for a null (baseline) period until the start of the next trial. All subjects were instructed not to wait for the stop-signals.

The stimulus remained on the monitor until subjects responded or until 1,250 msec elapsed. The default inter-stimulus interval is 2,000 msec and is independent of reaction time. Each trial starts with the presentation of the fixation cross, which is replaced by the Go trial stimulus after 250 msec.

3. Statistical analysis

All the data and two dependent variables, such as the NSRT and the SSRT, were analyzed. The SSRT was calculated by subtracting mean SSD from the untrimmed mean reaction time. The mean raw reaction time for all no-signal trials were calculated at the first (i.e., the NSRT), and then mean SSD is subtracted from this value.

The effect of each practice was determined using two-way ANOVA (groups: Blocked-SST, Random-SST × practice session: P1, P2, P3) with repeated measures of the two dependent variables, the NSRT and the SSRT. The paired t-test was used to compare the NSRT and the SSRT between the practice session and test session (post-test). All statistical analyses were performed using SPSS, version 15.0. A p value <0.05 was considered significant.

III. Results

Between the two groups, there was no significant difference in terms of gender, age, height, and weight, which are known to affect the performance of the SST task (Table 1). In the SSRT of each group, the main effect of practice level was statistically significant (p<0.05)(Table 2). The interaction between practice and group main effects was statistically significant, and it was the difference between the groups (p<0.05)(Table 2). In the NSRT

Table 1. General characteristic of each subject

	Blocked-SST group	Random-SST group
Gender (M/F)	14(6/8)	16(7/9)
Age (years)	21.93±2.20	21.94±1.98
Height (cm)	166.29±9.18	168.63±8.99
Weight (kg)	61.00±12.82	62.56±12.17

SST: Stop signal task

of each group, the main effect of practicelevel was not statistically significant (p>0.05)(Table 3), whereas the inter-action between practiceand group main effects was statistically significant, and it was the difference between the groups (p<0.05)(Table 3). Table 4 presents the SSRT and the NSRT scores in the post-test SST after practice of each task. After the random-SST group practiced, the SSRT was significantly decreased (p<0.05), whereas the NSRT was not significantly changed (p>0.05). After the blocked-SST group practiced, both the SSRT and the NSRT were increased but there were no significant change (p>0.05).

IV. Discussion

Stop function is considered to be a key component of executive control. In the current study, we found that both the SSRT and the NSRT was significantly decreased in the blocked-SST group, but not significantly changed in the random-SST group. In addition, the blocked-SST group was faster than the random-SST group in ongoing and stopping process times. In the post-test SST after practice of each group, the SSRT was significantly decreased in the random-SST group, but no significant reduction was observed in the blocked-SST group. In the NSRT of post-test SST, there were no significant changes in all groups, which suggests that the random-SST practice for three consecutive days resulted in a decrease in the internal processing times needed for a rapid stop to visual signals, because motor skill learning is acquired through random-SST practice.

Our findings showing a decline in stopping process times, were in line with previous SST experiments, which influenced by automatic processing through task goals can be primed.[16,21,27,28] These studies have reported that goal-directed actions can be started and guided to completion automatically

by information in the task environment. This means the

Table 2. Changes of the stopping process time from the visual stimuli at practice levels of both groups   (Unit: ms)

Group	SSRT			Practice	Group	Interaction (Practice x Group)
	P1	P2	P3			
Blocked-SST	235.06±49.75	203.96±52.52	177.96±53.32	0.04*	0.00*	0.00*
Random-SST	272.96±39.06	294.98±44.19	305.23±46.24			

*p<0.05
P1, 2, 3: Practice levels
SST: Stop signal task
SSRT: Stop-signal reaction time

Table 3. Changes of the ongoing process time from the visual stimuli at practice levels of both groups   (Unit: ms)

Group	NSRT			Practice	Group	Interaction (Practice x Group)
	P1	P2	P3			
Blocked-SST	732.90±50.13	701.37±52.69	665.29±58.36	0.15	0.01*	0.00*
Random-SST	777.22±143.07	832.69±151.93	805.47±160.54			

*p<0.05
P1, 2, 3: Practice levels
SST: Stop signal task
NSRT: No-signal reaction time

Table 4. The comparison of the stopping and ongoing process time between the last-practice and post-test on each group (Unit: ms)

Group	SSRT		P	NSRT		P
	last-practice	post-test		last-practice	post-test	
Blocked-SST	177.96±53.32	174.35±51.14	0.82	665.29±58.36	682.59±66.97	0.07
Random-SST	305.23±46.24	272.81±39.95	0.01*	805.47±160.54	839.33±175.48	0.06

*p<0.05
SST: Stop signal task
SSRT: Stop-signal reaction time
NSRT: No-signal reaction time

automatically activated goals interfered with performance, but the intentionally activated goals determined whether subjects actually respondedor stopped. Moreover, goal priming depended on the relevance of the task goal to the task context. This means that priming incongruent goals interfered with performance, but intentionally activated goals determined which response was executed. Accordingly, the goals of stopping can be activated automatically by implicating associations between irrelevant information in the task environment and task goals. It appears that executive control, such as stopping, can be triggered in both downward decisions and upward control, which reduces the need for intention.

Many previous studies have demonstrated behavioral changes in executive control influenced by differential recruitment of response selection and inhibition in the stop fun-ction.[7,15,22,29] The response inhibition in the stop function is one facet of response selection, such that inhibiting a response is an internal response involving a lack of movement. The response selection in the stop function is a form of cognitive control that involves selecting an appropriate goal-related response. Some studies have reported that a strong association was observed between the response selection and inhibition to be involved in controlled ongoing and stopping processes. Furthermore, other studies have revealed that the efficiency of response inhibition improves in concert with increases in the extent of the preparation ongoing before stop-signals and that this improvement can reduce the demand of response inhibition during the stopping process.[14] The sufficient preparation shortened the reaction time of the stop process (i.e., SSRT), whereas it reduced inhibition-related activity in imagining results. It appears that the shorter time of preparation cost the faster responses stop.

Accordingly, the stop functions of the SST correspond to the preparation cost of response conflict between selection and inhibition that suggests it may to some degree recruit stop processing before a stop-signal.

In the current study, we found that the random-SST efficiently improved stop functions which adjust response strategies to balance the opposing demands of the ongoing and the stopping for goal-related preparation. In addition, these findings showed that the random-practice for motor skill acquisition in the SST could provide a highly effective intervention and improve the ability of executive control in patients with cognitive disorders of stop functions. Combining blocked-practice with random-practice can improve monitoring or adjusting between response selection and inhibition, and it may be valuable rehabilitation training for therapeutic intervention. The limitation of this study was the lack of variety of stop-signals in stop-related movements. Additionally, factors, such as a person's motor performance ability and attention of goal-directed stop on the task, are crucial components that cannot be quantified. Thus, further studies will be required to ascertain the detailed mechanisms of motor skill learning in stopping and to investigatethe neurobehavioral connection between the ongoing and stopping process.

Author Contributions

Research design: Kwon JW
Acquisition of data: Kwon JW, Nam SH
Analysis and interpretation of data: Kwon JW, Nam SH
Drafting of the manuscript: Kwon JW
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