

Original Article

The effect of a concomitant stroop task during sit-to-stand tasks on postural control

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Abstract. [Purpose] This study aimed to explain the effect of a dual-task technology that utilizes motor and/or cognitive skills on the performance of major tasks, postural control, and gait consistency. [Participants and Methods] Eighteen healthy adults were divided into two groups: the single-word dual-task group and the control group (study 1). We enrolled 32 healthy adults to perform four-word Stroop (study 2) and sit-to-stand tasks simultaneously to determine the attentional demand for postural control and locomotion. [Results] The dynamic condition of postural control differed significantly between the single-task and single-word dual-task groups in Study 1. In Study 2, postural control in the four-word dual-task condition improved under both static and dynamic conditions. On comparing the results of studies 1 and 2, we found that during a four-word dual-task, healthy participants experienced a more significant decrease in postural sway than that experienced during the single-word dual-task. [Conclusion] Dual task of Stroop task with sit-to-stand could improve a postural control.

Key words: Dual-task, Postural control, Cognition

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INTRODUCTION

People must often perform several tasks simultaneously during their daily activities. A dual-task (DT) is a task that combines two motor tasks, or a motor and cognitive task, while keeping each target in mind^{1,2)}. However, the secondary task, which requires motor and/or cognitive skills, can impair an individual's performance, postural control, and gait consistency during the primary task³⁻⁵⁾.

Dual-task training, which combines cognitive and motor training, enhances memory and postural function⁶⁾. DT training can be beneficial in patients with various impairments. Studies have found that the postural function of patients with chronic stroke improved after DT training^{7,8)}.

We used DT procedures to evaluate the information-processing capacity of subjects performing two tasks simultaneously. If each task was completed correctly, the tasks were said to be independent, indicating that the attentional requirements of one task were not required to complete the other. However, if the participant's performance in one of the two tasks decreased compared to when the task is performed alone, this indicates that the attentional demands of the two tasks exceed the participant's attentional capacity⁹⁾. Stapleton et al. suggested that a decrease in attentional capacity may be associated with an increase in attentional demands involved in performing a cognitive task under DT conditions¹⁰⁾. Ruffieux et al. claims that when more attentional resources are required or attentional capacities are limited, even simple motor skills can become difficult to perform simultaneously with an attention-demanding task. If processing capacities are exceeded, adding a concurrent task increases the overall attentional demands and may cause interference between the two tasks¹¹⁾. Therefore, employing specific secondary task practice is important to acquire skills under DT conditions¹²⁾, as the type of secondary task can influence postural control in adults¹³⁾. Some studies claim that the complexity and type of secondary tasks performed

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while performing motor tasks affect postural control. The type of secondary task or domain of information processed while performing the secondary task may impact the patients' balance during DT training while performing a motor task^{14, 15}).

Hiyamizu et al. demonstrated that the Stroop test is a cognitive task used to assess the cognitive control and is commonly used in neuropsychology and cognitive neuroscience. Furthermore, their findings show that the after Stroop task training resulted in increased smoothness in cognitive activity while performing motor tasks in daily life¹⁶. In the Stroop task, the participants name the ink color that the name of a color is written in. If the color and word (e.g., "red" in red ink) are congruent, the task is straightforward. However, the task becomes more complex with when the color and meaning of the word are incongruous (e.g., "Blue" in red ink)¹⁷. This is because reading is a more practical and automatic ability than naming colors, so the participants must exert attentional control to overcome their tendency towards reacting to the word rather than to the color^{18, 19}).

The researcher used the dual-task paradigm and found an interaction between posture control and cognitive tasks when they are completed simultaneously. They pointed out that posture control does not happen automatically but requires cognitive participation¹¹⁻¹³). Stroop test is proven to be used to assess cognitive ability¹⁶).

Accordingly, we increased the difficulty of Stroop test to explore the interaction between cognition and posture control. Two complementary studies were conducted within this complex context to investigate the effect of the DT of more difficult Stroop tasks on postural control in healthy participants. In Study 1, we explored the effects of a Stroop task on posture among healthy adults by comparing single-task and DT conditions. In Study 2, we increased the difficulty of the Stroop task.

PARTICIPANTS AND METHODS

Fifty healthy participants were involved in this study. We conducted a non-clinical quasi-experimental design with single-blind allocation concealment. Eighteen healthy adults were divided into two groups: the single-word dual-task group (SDT) and the control group. A flow diagram is shown in Fig. 1A (Study 1). In Study 1, participants were randomly allocated to the SDT (n=9) or control groups, respectively (n=9). Participants in the SDT group were asked to perform a single-word Stroop task, while the control group only watched the Stroop task without saying any words.

The inclusion criteria were as follows: (1) 20 years of age or older; (2) no neurologic or musculoskeletal diagnoses, such as orthopedic involvement or significant visual or auditory impairments. If they conformed to the inclusion criteria, the participants were randomly allocated to each group. We explained the study protocol to the participants before obtaining informed consent. The study was approved by the Research Ethics Committee of the Tokyo Metropolitan University (No. 19105).

Study 2 has the same inclusion criteria as Study 1. Thirty-two healthy adults were divided into single-task and DT groups. A flow diagram is shown in Fig. 1B (Study 2). In Study 2, the participants were randomly allocated to either the four-word DT group (n=16) or the single-task group (n=16).

The intervention lasted for 1 min. An unstable cushion was placed on the chair seat. During the single-task and DT conditions, the participants were asked to keep changing from sitting to standing as a motor task. In the single-task condition, the participants were asked to go from sitting to standing at a set speed using a metronome without using their upper limbs, and only watch the Stroop task without saying any words. All the previous procedures were repeated in the DT condition; however, the participants had to perform the Stroop test while repeatedly going from sitting to standing.

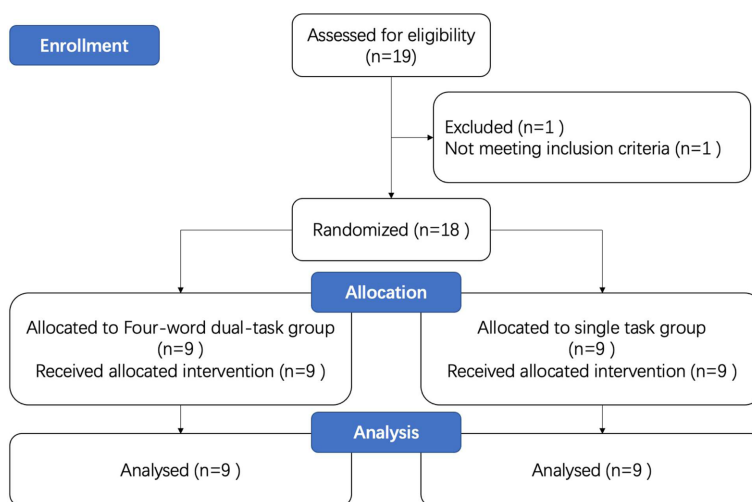


Fig. 1A. Flow diagram in Study 1.

Four different words appeared on the monitor. The ink color matched three of the words (color names), while one was not matched (e.g., “red” in yellow letters). Twelve pages were added during the experiment. The stimulus was displayed in front of the participants on a 2-meter computer with a white background. The subjects were asked to identify and state the color of the mismatched word. The time interval between the inserted words randomly changed between 100 ms and 200 ms to avoid a pattern being noticed.

Participants tried to maintain their balance while standing on a pressure plate (ANIMA GRAVICORDER G-620, Tokyo, Japan) with their hands crossed in front of their chest to maintain a safe and relaxed stance. The participants were given a brief orientation to the setup to find a suitable position for their feet on the standing area. The participants’ foot positions were marked on the plate to ensure reproducibility of the position.

Each group completed the standing balance test, which required four conditions. In the static standing test, participants were asked to maintain their posture with their eyes open or closed while remaining as still as possible. In the dynamic standing test, participants were asked to incline their posture forwards and/or backwards. Participants were required to incline forward or backward while keeping their back as straight as possible, rather than bending their upper body. Each condition required that the participants look at a point two m away at eye level for 30 s. Standing balance tests were completed before and after the intervention.

We used two-way repeated-measures analysis of variance to compare changes in outcome between the groups at two different time points. The groups and times were used to assess the presence or absence of interaction among the factors. If an interaction was present, a simple main effect test was performed. All analyses were conducted using the Statistical Package for Social Sciences (SPSS) version 26.0 (IBM Corp., NY, USA), and significance levels were set at $p < 0.05$.

RESULTS

Table 1 presents the demographic characteristics of the study population. Eighteen participants were eligible, of which 11 were men and 7 were women). The experiment and control groups had average ages of 26.00 ± 5.43 and 27.78 ± 5.12 years, respectively.

There were no differences in demographic characteristics such as gender, age, height, or weight between the groups. None of the participants in either group experienced severe adverse events during the study period.

The outcomes are shown in Table 2. None of the outcomes of the main effects of the groups were significant, except for MY and LNG in the forward condition, and MY in the backward condition. The effect of time was not significant. No

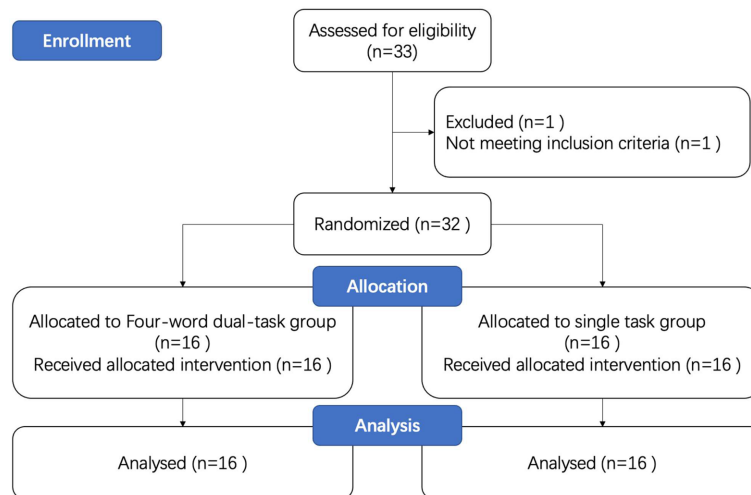


Fig. 1B. Flow diagram in Study 2.

Table 1. Demographic data of the two groups in Study 1

	SDT (n=9)	Control (n=9)	p-value
Age (years)	26.0 ± 5.4	27.8 ± 5.1	0.37
Gender (M/F)	5/4	6/3	
Height (cm)	164.1 ± 7.8	163.22 ± 10.44	0.85
Weight (kg)	58.3 ± 4.8	60.9 ± 11.8	0.61

significant interactions were observed.

Table 3 presents the demographic characteristics of the study population. A total of 32 people were eligible for the study, which included 22 males and 10 females. The experiment and control groups had average ages of 28.38 ± 5.02 and 28.13 ± 4.99 years, respectively.

There were no differences in demographic characteristics such as gender, age, height, or weight between the groups. None of the participants in either group experienced severe adverse events during the study period.

The outcomes are shown in Table 4. The outcomes of the main effects of the groups were not significant, except for the RMS of the eyes open, forward, and backward conditions. The primary effect of time was not significant, except in the MY of the forward condition, and MY, LNG, and RMS of the backward condition. The interactions were significant in the eyes open-LNG, eyes-closed LNG, forward-MY, and backward-MY. The other outcomes showed no significant interactions.

DISCUSSION

The present study explored the effect of adding the difficulty to Stroop task on the postural control by comparing the training with Stroop task and without Stroop task on healthy participations.

The study is to explore the effect of the Stroop task on posture control. We used the COP monitor to evaluate the postural control indicated by the COP-MX, COP- MY, COP-length and COP-RMS. We found that the dynamic condition of postural control benefitted significantly between single-task and SDTs in Study 1 and postural control benefitted more from single word DTs. In Study 2, comparing the individuals in the single-task and four-word DT conditions, postural control of the

Table 2. Effect of intervention between the two groups at baseline in Study 1

	Experiment (n=16)	Control (n=16)	p-value
Age (years)	28.4 ± 5.0	28.1 ± 5.0	0.89
Gender (M/F)	10/6	12/4	
Height (cm)	166.3 ± 8.2	167.3 ± 7.2	0.73
Weight (kg)	62.5 ± 12.7	66.1 ± 12.8	0.41

*p<0.06, **p<0.01, ***p<0.001.

Table 3. Demographic data of the two groups in study 2

Variable	Data of two groups before and after intervention				Group	Time	Group×Time
	SDT group		Control group				
	Pre-test	Post-test	Pre-test	Post-test			
Static							
Eyes open MX	-0.76 ± 0.89	-0.53 ± 1.10	0.12 ± 0.59	0.12 ± 0.69			
Eyes open MY	-2.64 ± 1.96	-3.02 ± 1.83	-2.44 ± 1.30	-2.25 ± 1.65			
Eyes open LNG	16.27 ± 6.08	16.03 ± 6.08	17.21 ± 5.10	19.78 ± 7.02			
Eyes open RMS	0.59 ± 0.45	0.58 ± 0.44	0.69 ± 0.49	0.89 ± 0.73			
Eyes closed MX	-0.50 ± 0.93	-0.56 ± 0.98	0.02 ± 0.45	0.04 ± 0.71			
Eyes closed MY	-2.72 ± 1.72	-2.92 ± 2.11	-2.32 ± 1.18	-2.29 ± 1.77			
Eyes closed LNG	20.26 ± 7.51	18.95 ± 6.72	21.07 ± 7.63	26.53 ± 10.28			
Eyes closed RMS	0.43 ± 0.23	0.37 ± 0.16	0.46 ± 0.15	0.50 ± 0.18			
Dynamic							
Forward MX	-0.49 ± 1.24	-0.35 ± 1.35	-0.25 ± 0.76	-0.31 ± 0.73			
Forward MY	3.83 ± 1.32	4.27 ± 1.37	2.77 ± 2.51	2.79 ± 2.64	*		
Forward LNG	25.85 ± 9.11	24.22 ± 8.81	29.59 ± 11.95	31.57 ± 13.94	*		
Forward RMS	1.04 ± 0.60	1.07 ± 0.89	0.98 ± 0.51	1.04 ± 0.55			
Backward MX	-1.04 ± 1.12	-1.14 ± 1.02	-0.05 ± 0.82	-0.22 ± 0.99			
Backward MY	-7.70 ± 2.48	-8.07 ± 2.93	-5.19 ± 1.74	-5.07 ± 2.13	**		
Backward LNG	28.71 ± 14.44	28.50 ± 13.05	33.03 ± 11.23	34.21 ± 14.45			
Backward RMS	0.69 ± 0.33	0.65 ± 0.28	0.79 ± 0.58	0.80 ± 0.75			

MX: mean value of COP in the left-right direction; MY: mean value of COP in the anterior-posterior direction; LNG: Length of the trajectory at the COP; RMS: Root Mean Square.

*p<0.05, **p<0.01, ***<0.001.

Table 4. Effect of intervention between the two groups at baseline in Study 2

Variable	Data of two groups before and after intervention				Group	Time	Group×Time
	Experiment group		Control group				
	Pre-test	Post-test	Pre-test	Post-test			
Static							
Eyes open MX	0.15 ± 0.82	0.21 ± 0.92	0.00 ± 0.58	-0.18 ± 0.64			
Eyes open MY	-1.95 ± 1.91	-1.15 ± 1.87	-1.70 ± 1.58	-1.50 ± 2.14			
Eyes open LNG	33.83 ± 8.41	31.98 ± 7.82	33.95 ± 7.08	35.05 ± 7.06			**
Eyes open RMS	0.70 ± 0.33	0.53 ± 0.29	0.90 ± 0.51	1.06 ± 0.59	*		
Eyes closed MX	0.11 ± 0.71	-0.27 ± 0.96	-0.05 ± 0.52	-0.22 ± 0.63			
Eyes closed MY	-1.89 ± 1.95	-1.21 ± 1.82	-1.67 ± 1.52	-1.59 ± 1.95			
Eyes closed LNG	37.20 ± 10.02	33.53 ± 8.24	36.38 ± 9.07	38.36 ± 8.84			**
Eyes closed RMS	0.65 ± 0.45	0.52 ± 0.34	0.58 ± 0.41	0.61 ± 0.45			
Dynamic							
Forward MX	0.04 ± 0.76	-0.18 ± 0.88	-0.11 ± 0.60	-0.35 ± 0.74			
Forward MY	2.55 ± 2.84	3.50 ± 2.63	3.07 ± 2.74	3.21 ± 2.63		**	**
Forward LNG	43.27 ± 11.65	42.74 ± 10.35	42.01 ± 9.87	43.13 ± 9.55			
Forward RMS	1.11 ± 0.58	1.10 ± 0.72	1.32 ± 0.70	1.67 ± 1.30	*		
Backward MX	0.06 ± 0.98	-0.03 ± 1.01	0.06 ± 0.81	-0.25 ± 0.95			
Backward MY	-5.28 ± 1.51	-6.04 ± 1.64	-5.29 ± 1.50	-5.18 ± 1.74		**	**
Backward LNG	44.62 ± 10.39	42.09 ± 8.81	46.30 ± 10.36	45.66 ± 10.87			
Backward RMS	1.08 ± 0.69	0.70 ± 0.40	1.31 ± 0.96	1.13 ± 0.78	*	**	

MX: mean value of COP in the left-right direction; MY: mean value of COP in the anterior-posterior direction; LNG: Length of the trajectory at the COP; RMS: Root Mean Square.

*p<0.05, **p<0.01, *** p<0.001.

DT condition was improved under static and dynamic conditions. However, comparing the results of Study 1 and Study 2 in healthy participants indicated that performing a four-word DT produced a significant decrease in postural sway that was better than that of the single-word DT.

The ‘posture-first’ principle suggests that cognitive tasks cause increased balance interference, as balance is prioritized^{20, 21}). Vaillant et al. included 68 osteoporotic females >70 years of age in a study on dual-tasking balance training and found that balance improved after the DT in the one-leg balance test and Timed Up and Go test in the single-task and DT groups. The DT group exercised while performing standardized cognitive tasks, such as reciting poems, counting out loud in increments of two, three, or five, and reciting lists of objects or places²²). Pellecchia et al. assessed the effects of DTs on postural stability among healthy young participants, and the cognitive task was counting backward in increments of 3. Based on their results, postural control was significantly improved in the DT group compared with that of the control group²³). Hiyamizu et al. included forty-three subjects (all >65 years old) who were randomly assigned to either a DT or control group. The Stroop task was set as the cognitive task in the DT group. Their results suggest that DT balance training in older adults improves DT performance in terms of standing postural control¹⁶). We used the Stroop task in Study 1 and found that our findings are similar to those of Hiyamizu et al, who discovered that postural control in healthy adults improved after DT training compared to that observed after single-task conditions. In Study 2, we used the more difficult Stroop task and found that postural control improved after DT training, and the participants’ postural control was better than that observed in Study 1. The Stroop task is a cognitive task that is often used in neuropsychology and cognitive neuroscience to assess the cognitive control. According to research on brain imaging, a brain area related to working memory, such as the supra-marginal bilateral inferior frontal regions, may be stimulated. As a result, this area is assumed to contain a component required for smooth standing postural control¹⁸). The findings of this study indicate that postural control and cognitive function are not independent systems, which further supports the posture-first principle.

The physiological explanation for our findings is that cerebral processing under DT conditions changes the way the central nervous system controls postural stability. Balance is preserved under normal circumstances by integrating sensory information from the visual, vestibular, and somatosensory systems^{24, 25}). The input is obtained from limb positioning and transmitted to the basal ganglia. This signal is integrated with planned actions developed in the premotor and supplementary motor cortices in the cerebellum. Visual and somatosensory inputs typically provide the majority of information required to maintain postural stability²⁶).

To explain the preservation or improvement in postural control during the DT condition, Vuillerme and Nafati suggested two additional hypotheses. The first hypothesis proposes that increased concentration during a reaction-timed cognitive task

results in increased muscle stiffness and improved postural control²⁷). Hunter et al. supported this theory by demonstrating that medial-lateral COP movement was reduced during a balance test in participants who simultaneously performed visual cognitive tasks²⁸). Our results also confirmed this view, the postural control of participations improved after the dual-task training.

The second hypothesis proposes that DT conditions improve sensory-motor control²⁹). The present study revealed that postural stability was improved following participants on performing the dual task. By integrating a secondary cognitive task into the DT system, we can reflect sports situations better by the day, forcing individuals to focus on the secondary cognitive task while having postural stability to facilitate the automatic processes described previously²⁷). Moreover, our results confirm a previous study that indicated postural stability was improved by Stroop task. Moreover, our result showed that after difficulty Stroop task postural control was improved better than simple Stroop task.

According to the task integration hypothesis, participants can improve task-coordination skills by practicing two tasks simultaneously (instead of one at a time)³⁰). One potential explanation may be that improving postural control requires effective integration and coordination of the two tasks learned during DT training.

Silsupadol et al. demonstrated the benefits of dual-tasking according to the task integration hypothesis, which states that practicing two tasks simultaneously improves task coordination skills³⁰). Similarly, Kramer et al. observed significant benefits in the priority variable benefits and suggested that participants should learn to coordinate between two tasks under variable priority training conditions³¹). In addition, some brain centers with DT processing have shown reduced activation following practice, which suggests that lower processing power is required³²). Several studies have also proposed DTs as cognitive therapy in patients with attention deficiencies and cognitive impairments^{33, 34}). Wollesen et al. found that DT training systems can also improve cognitive skills³⁵). According to Hiyamizu, improvements in cognitive efficiency can lead to a smoothing of cognitive activities while maintaining static and dynamic postures, which may prevent participants from falling¹⁶). Our findings are similar to those of Hiyamizu who found that postural control in healthy adults improved after DT training compared to single-task conditions.

Huxhold et al. observed that a perceptual-motor task was facilitated when the practice was paired with a difficult secondary task, but not when the practice was paired with an easy secondary task. The authors suggested that the difficulty of the secondary task induced a positive vigilance effect, which benefitted the primary task performance, which was measured at delayed retention. In other words, participants may have increased the use of attentional resources when handling difficult secondary tasks. Increased cognitive effort during practice is a well-recognized factor that benefits motor learning³⁶).

This study has several limitations. The first is that we did not assign cognitive tasks, choosing to only observe motor and motor cognitive tasks. Therefore, it is unclear whether the postural control training was effective under cognitive task conditions. The second limitation was that we included healthy individuals in this study. However, it is noteworthy that intervention with DT balance education improved postural control, even in healthy individuals.

In conclusion, the main issue addressed in this experiment was the measurement of postural stability during different DT conditions. In DT conditions under static and dynamic conditions, participants exhibit improved postural control in single-task conditions, which aligned with the posture-first principle. A significant decrease in postural sway was observed in participants who were subjected to four-word DT conditions, which was larger than that observed in the simple DT condition.

As a clinical implication, we suggested further study involving patients by difficulty cognitive task training to actual hemiparesis and stroke patients. Further studies are needed to explore the interaction between postural control and cognition before implementing it to patients.

Conflict of interest

There are no conflicts of interest to declare.

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