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Original Article

Longitudinal changes in the conventional and modified timed up and go tests and the degree of care in elderly individuals with mild disequilibrium

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Abstract. [Purpose] The TUG and c-TUG are tests designed to test a person's physical mobility during rehabilitation. However, based on differences in the degree of care an individual receives, results from these tests may show delayed times. Longitudinally, measured physical function in elderly persons who require support using the timed up and go test (TUG) as well as TUG while grasping a cup (c-TUG) to determine the differences in the degree of care being provided to individuals. The study aimed at finding methods of improving preventive care. [Subjects and Methods] Care Needs Categories 1 (10 people) and 2 (8 people), measured the time required and the number of steps needed for TUG and c-TUG. The average age was 80.1 ± 5.2 years in Care Needs Categories 1 and 81.6 ± 5.9 years in Care Needs Categories 2. The participants were monitored every 3 months for 1 year. [Result] Over the course of one year, the rate of change in the time required to perform the c-TUG increased on the left side for individuals in Care Needs Category 2. In terms of the degree of care, the required time for individuals in Care Needs Categories 2 and the number of steps increased compared to those in Care Needs Categories 1. [Conclusion] Our findings suggest that the TUG and c-TUG reflect the mobility of elderly people with mild disequilibrium, and that results of non-dominant hand c-TUG evaluations could reflect differences in the degrees of care provided.

Key words: elderly with mild disequilibrium, TUG, c-TUG

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1. INTRODUCTION

There are various methods for evaluating mobility among patients in rehabilitation. Of these, the timed up and go test (TUG), proposed by Podsiadlo[1)], is widely used in the evaluation of the elderly. TUG is a method for measuring and timing patients while they are observed rising from an arm chair, walking 3 meters, turning, walking back, and sitting down again. TUG is considered to be a useful method for evaluating mobility in the elderly. According to Podsiadlo[1)], if the time required is less than 10 seconds, the person is considered to be completely self-sustaining. If the required time is 10–20 seconds, the transfer is considered to be mainly self-sustaining, and the person can independently climb stairs or go out alone. If the time is 30 seconds or longer, support for most activities is necessary. In the frail elderly, 13.5 seconds is regarded as the cutoff value indicating fall risk[2)].

In the Physical Therapy Clinical Practice Guidelines issued by the Japanese Physical Therapist Association, TUG is a "Recommended Grade A" test in the evaluation of the physically fragile elderly.

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TUG is said to correlate with the Berg balance scale for elderly people, as well as with the Barthel Index. In addition, TUG correlates with functional indicators, activity restrictions, and participation restrictions. TUG can be influenced by aging and environmental factors resulting in changes in intellectual function, and is reflected in activity and social participation[3]. The measured time reliably correlates with functional physical fitness and mobility in elderly people[4]. With respect to the relationship between TUG and movement ability[5], lower limb muscular strength and mobility are interrelated in the elderly. Therefore, it is necessary to maintain lower limb muscle strength to promote continued mobility. However, past research reflects movement ability at the time of the evaluation without discussing future changes. In many cases, various actions are performed simultaneously and it is unlikely that the ability to perform an entire action can be unveiled in a single motion evaluation. In a report discussing the relationship between the value of TUG with a cognitive task and fall risk[6], the dual task is useful as a method of evaluating fall risk in the elderly. In particular, it can be utilized as a more effective evaluation method by conducting it among elderly people who have little decline in exercise and cognitive function. In terms of dual tasks that incorporate a cognitive action, Olsson et al. [7] reported that the TUG manual can be used for elderly people with dementia. The TUG manual is a method of conducting TUG while the subject holds a cup containing water. There are also reports[8] that have examined the cognitive function of community-dwelling elderly residents performing TUG. Unfortunately, there are few reports on elderly people with mild disequilibrium, and each of those reports included subjects with different comorbid conditions, making it difficult to compare the results.

With reference to the TUG manual, devised a method of performing TUG while the participant holds a cup filled with 500 cc of water (c-TUG). The c-TUG test begins with the individual in a seated position on a chair. The individual is then instructed to hold a cup containing 500 cc of water with one hand after standing up. The participant is instructed to approach a target 3 meters away while holding the cup of water, and then return to the original chair, all while trying not to spill the water. After returning to the chair, the participant is instructed to set the cup down. The time required for this entire cycle is measured[9]. This c-TUG evaluation in elderly people with mild disequilibrium[10] showed the interaction between TUG and c-TUG based on the time required to perform the tasks and the degree of care received. A significant difference was observed between the required time and the number of steps taken because of differences in degrees of care.

In this study, longitudinally evaluated a series of elderly persons with mild disequilibrium using TUG and c-TUG. Furthermore, examined the changes and determined whether any of them resulted from differences in the degree of care. The goal of our study was to find methods of improving preventive care rehabilitation.

2. SUBJECTS AND METHODS

The subjects were 20 elderly femail requiring support, who were identified as Care Needs Category 1 or 2 in the Japanese long-term care insurance system, and who used weekly rehabilitation for long-term care prevention. According to the degree of nursing care, there were 10 subjects who fell into the Care Needs Category 1, and 8 who met criteria for Care Needs Category 2. There were excluded those with cerebrovascular disease and those with cognitive deficits. Data were collected from 18 subjects over the course of 1 year, 10 from Care Needs Category 1, and 8 from Care Needs Category 2. Prior to the start of the research, all subjects were provided with written and verbal explanations about the study, including the purpose and content of the research. Informed consent was obtained from all subjects. This research was conducted with the approval of the International University of Health and Welfare Ethics Committee (approval number: 14-Ig-60).

The data collection period was from December 2015 to December 2016. The evaluations included a total of 5 measurements of physical function at the following time points: start time, 3 months, 6 months, 9 months, and 12 months. The subjects collectively performed exercises prescribed by physiotherapists for one hour once a week. Subjects in Care Needs Categories 1 and 2 performed the same exercises. The measurements included: the time required for TUG and the number of steps, the time required for c-

TUG when holding a cup in the left and right hands, and the number of steps. To measure TUG and c-TUG, the maximum effort walking speed was recorded and the required time and number of steps were measured. For c-TUG, the table upon which the cup was placed was 67 cm high x 74 cm long x 39 cm wide. The sitting position was set at the end of the table, with the subject's feet flat on the ground, and the cup was placed about 10 cm from the front end of the table. In each case, "right c-TUG" was measured when carrying a cup in the right hand, and "left c-TUG" when carrying a cup in the left hand.

For each item of physical function, the mean value and standard deviation were calculated for each evaluation month in both Care Needs Categories 1 and 2. The rate of change in the data from the start month to the second and later evaluation months was calculated. The starting month of the measurement month is denoted as 1M, 3 months after as 3M, 6 months after as 6M, 9 months after as 9M, and 12 months after as 12M.

The Mann-Whitney U test was used to analyze each of the attribute items for the subjects in both Care Needs Categories 1 and 2. The Friedman test was conducted to evaluate each body composition item, data of each item of Care Needs Categories 1 and 2. When a significant difference was observed, multiple comparisons were made using Wilcoxon 's signed rank test. In each evaluation month, comparisons and examinations were conducted using the Mann - Whitney U test to compare Care Needs Categories 1 and 2. SPSS statistics 23 (IBM, Armonk, NY, USA) for windows was used as the statistical software, and the significance level was set at 5%.

Table1 Attributes of Target Subjects

	height(㎝)	weight(kg)	age(years)	BMI(kg/㎡)
Care Needs Categories 1	147.2 ± 4.0	50.5 ± 6.8	80.1 ± 5.2	23.2 ± 2.3
Care Needs Categories 2	150.4 ± 5.8	55.2 ± 8.7	81.6 ± 5.9	24.3 ± 2.7

Data are presented as means ± SDs

3. RESULTS

The basic attributes of the participants are shown in Table 1. There were no significant differences between the participants in Care Needs Categories 1 and 2 in all of the basic attributes.

Table 2 shows the required time for TUG, and the left and right c-TUG according to the degree of care. Table 3 shows the number of steps for TUG and for right and left c-TUG, as well as the rate of change of time needed to perform TUG. Table 4 shows the rate of change for right and left c-TUG, and the rate of change in the number of steps for c-TUG is shown in Table 5.

Based on the Friedman test analysis, Care Needs Category 1 showed no significant difference in the time required for TUG or for left and right c-TUG (Tables 2 and 3). In Care Needs Category 2, significant differences were found between the time required for left c-TUG, its rate of change, and the number of steps required (Tables 2, 3, 4, and 5). No significant difference was observed in the other parameters. Based on the multiple comparison test results, a significant difference was observed in the rate of change in the time required to perform left c-TUG (3 M and 6 M, 3 M and 9 M, 3 M and 12 M) (Table 4).

In comparing Care Needs Category 1 to Care Needs Category 2, the required times for TUG, right c-TUG, and left c-TUG were significantly delayed in subjects in Care Needs Category 2 compared to those in Care Needs Category 1 in all evaluation months (Table 2). TUG, right c – TUG, and left c -TUG, except for TUG at the 1 M time point, were significantly increased with respect to the time required to perform the activities among subjects in Care Needs Category 2 group compared those in Care Needs Category 1 group (Table 3). There were no significant differences in the degrees of care with respect to the required times and rate of change in the number of steps (Tables 4 and 5).

Table2 Time required for TUG and c-TUG by Care Needs Category (seconds)

	TUG		right c-TUG		left c-TUG	
	C1	C2	C1	C2	C1	C2†
1M	8.3 ± 1.9	12.9 ± 3.7*	10.3 ± 1.6	16.7 ± 4.3*	10.7 ± 0.9	17.8 ± 4.9*
3M	8.3 ± 1.5	13.0 ± 3.1*	10.2 ± 1.4	17.5 ± 5.6*	10.3 ± 1.5	16.8 ± 4.3*
6M	8.5 ± 1.3	13.4 ± 3.2*	10.2 ± 1.4	18.0 ± 4.6*	10.7 ± 1.4	18.4 ± 4.3*
9M	8.5 ± 1.3	12.6 ± 3.2*	10.3 ± 1.7	17.4 ± 4.7*	10.8 ± 2.1	18.2 ± 4.5*
12M	8.5 ± 1.4	12.9 ± 3.3*	10.1 ± 1.4	18.2 ± 5.4*	10.5 ± 1.5	18.0 ± 4.7*

C1 : Care Needs Categories 1 C2 : Care Needs Categories 2 TUG: Timed up and go test c-TUG: Timed up and go test while grasping a cup

＊ : Significant difference between degree of care, $p < 0.05$ † : Significant difference over the year, $p < 0.05$

Table3 Number of steps required for TUG and c-TUG by Care Needs Category (step)

	TUG		right c-TUG		left c-TUG	
	C1	C2	C1	C2	C1	C2†
1M	15.7 ± 1.6	20.5 ± 5.2	17.2 ± 1.0	22.8 ± 5.3*	17.4 ± 1.3	23.4 ± 5.4*
3M	15.3 ± 1.3	19.3 ± 4.7*	17.2 ± 0.8	22.6 ± 4.7*	17.2 ± 0.8	21.6 ± 4.4*
6M	16.0 ± 1.3	20.4 ± 4.2*	17.4 ± 1.0	23.0 ± 4.0*	17.4 ± 0.8	22.4 ± 3.5*
9M	15.9 ± 1.3	20.0 ± 4.1*	17.3 ± 1.1	22.8 ± 4.5*	17.3 ± 1.1	22.6 ± 3.7*
12M	15.8 ± 1.2	20.1 ± 4.5*	17.4 ± 1.3	23.8 ± 5.6*	17.4 ± 1.6	23.0 ± 4.4*

C1 : Care Needs Categories 1 C2 : Care Needs Categories 2 TUG: Timed up and go test c-TUG: Timed up and go test while grasping a cup

＊ : Significant difference between degree of care, $p < 0.05$ † : Significant difference over the year, $p < 0.05$

Table4 Percent change in time required to perform the TUG and c-TUG according to Care Needs Category (%)

	TUG		right c-TUG		left c-TUG	
	C1	C2	C1	C2	C1	C2†
1M→3M	0.4	0.9	´-1.2	4.7	´-4.5	´-5.2☆
1M→6M	2.4	3.6	´-1.0	7.9	´-0.3	3.8☆
1M→9M	2.2	´-2.3	´-0.3	4.5	0.6	2.6☆
1M→12M	3.0	´-0.1	´-2.3	9.3	´-1.9	1.5☆

C1: Care Needs Categories 1 C2: Care Needs Categories 2 TUG: Timed up and go test
c-TUG: Timed up and go test while grasping a cup
☆ : There is a significant difference in the month, $p < 0.05$ † : Significant difference over the year, $p < 0.05$

Table5 Change in rate of TUG and c-TUG step number by Care Needs Category (%)

	TUG		right c-TUG		left c-TUG	
	C1	C2	C1	C2	C1	C2†
1M→3M	´-2.5	´-6.1	0	´-0.5	´-1.1	´-7.5
1M→6M	1.9	´-2.4	1.1	1.1	0	´-4.3
1M→9M	0.3	´-3.0	0.6	0	´-0.6	´-3.2
1M→12M	0.6	´-1.8	1.2	4.4	0	´-1.6

C1: Care Needs Categories 1 C2: Care Needs Categories 2 TUG: Timed up and go test
c-TUG: Timed up and go test while grasping a cup
† : Significant difference over the year, $p < 0.05$

4. DISCUSSION

In this study, measured the time required and the number of steps taken for TUG as well as left and right c-TUG. As a result, temporal changes over the course of the year showed significant differences in the time required and number of steps for left c-TUG among subjects in Care Needs Category 2. Otherwise no significant differences were observed.

Elderly people with mild disequilibrium require some support for routine activities but their mobility is often maintained. Even for the subjects in this study, both indoor and outdoor mobility capabilities were maintained from start to finish. TUG is useful for reflecting mobility in generally healthy elderly persons[11)]. However, in this study, there were no significant differences throughout the year for subjects in Care Needs Category 1 or 2 with respect to TUG. This suggests that TUG and c-TUG are useful for evaluating the state of mobility ability in the general elderly population, as well as in elderly persons with mild disequilibrium.

According to Friedman's test, there was no significant difference in the required time or number of steps between TUG, right c-TUG, and left c-TUG throughout the year among subjects in Care Needs Category 1. However, for those in Care Needs Category 2, a significant difference was observed between the time required for left c-TUG and the number of steps. As a result of the multiple comparison, the rate of change in the required time for left c-TUG was significantly higher. It is likely that the significant difference was observed in left c-TUG because most subjects in this study were right-handed and the left hands were the non-dominant hands. In everyday life, it is easy to move about indoors while holding a cup in the dominant hand. However, it seems that performing c-TUG with the non-dominant hand may have led to a delay in the time required to complete the task compared to other conditions. In addition, the fact that the difference appeared only among subjects in Care Needs Category 2 means that c-TUG with the non-dominant hand is both a dual task and an unfamiliar behavior. Additionally, subjects in Care Needs Category 2 less physical function was required, and it seemed that the degree of difficulty of the task increased. Therefore, it is possible to discriminate between the differences in degree of care by performing c-TUG under the condition of a load in the non-dominant hand.

Comparing the caregiving degrees, TUG, and left and right c-TUG significantly delayed the time required to perform the task for subjects in Care Needs Category 2. Additionally, the number of steps was significantly increased compared to that of subjects in Care Needs Category 1. This result confirms the interaction identified in a previous study[10)]. Simultaneously, c-TUG is an evaluation method reflecting the difference in degrees of care over time. There are reports[3)] that TUG is useful for forecasting the decrease in mobility in elderly people requiring long-term care. In those studies, elderly people with mild disequilibrium were not included. In other words, TUG is useful as a test that can sufficiently reflect mobility, even in elderly people with mild disequilibrium. Furthermore, it is important to add not only conventional TUG, but also to add the task of grabbing a cup, which is a routine operation in c-TUG. As a result, a series of motion control actions, including direction changes, control of postural balance of the upper limbs and trunk during upper limb manipulation, visual control to stabilize the water, and attention to performing the task of not spilling water are reflected.

For c-TUG in this study, added a cup grasping operation to the normal TUG operation via a cup filled with 500 cc of water, and directed the participants to perform c-TUG "doing so as not to spill". In fact, none of the participants spilled water from the cup at the time c-TUG was enforced. In the evaluation of dual tasks in the elderly, cognitive tasks are often added. In this study, the additional task is one that is done in everyday life and is familiar to the elderly. In dual tasks, the ability to understand two issues and process that information is required. Among them, selective attention is required and is considered necessary to perform the action. However, selective attention decreases with age. There is a decline in the information processing speed and a suppression of information processing with increasing age and decreased attention span. In elderly people aged 65 years or older, reports[12] using dual tasks show decreased processing capability for both tasks when two tasks are performed simultaneously. Even in home-independent senior citizens, if the physical and mental functions are low and dual tasks are performed, the amount of attention paid to walking is reduced due to the processing of sub-tasks. At the same time, walking behavior motions become slow[13]. Subjects performing c-TUG are instructed to perform the function of "carrying water so as not to spill". However, if the information processing ability is deteriorated by adding the instruction to "perform action as soon as possible", there a delay in the time required to perform the task and an increase in the number of steps. Furthermore, in the case of non-dominant hands, the operation itself was unfamiliar. Therefore, more attention and greater execution functions are required, the information processing load is increased, and the time required and number of steps are influenced.

Considering c-TUG with regard to attitude control in the elderly, the ability to move the center of gravity and the ability to correct and retain posture in an unstable situation tends to decrease with the aging process. This phenomenon is described in a report that strongly relates the fear of falling and the amount of living activity[14]. In addition, falls in older people are more closely related to disturbance load responses and balancing functions during voluntary exercise than static posture holders[11]. Therefore, c-TUG is thought to delay the time required for task performance due to deterioration of trunk stability when performing the cup-carrying operation. Decreases in mobility accompany decreases in activity. The c-TUG operation in this study involves an action performed with a cup, keeping a cup at TUG enforcement, and the action to place a cup in a set location. However, each action is regarded as a series of actions, and it is uncertain which operation primarily affected the delay in the time required to perform the task.

The results of this study showed that the difference in the time required for c-TUG compared to TUG occurred throughout the year, and that these changes were significant only in left c-TUG among subjects in Care Needs Category 2. Furthermore, because of the difference in degree of care, c-TUG can identify elderly people with mild disequilibrium based on the type of care received, even if TUG cannot elicit this distinction. Although TUG is used as an indicator of personal mobility, changes in movement ability in the future do not become clear. By distinguishing the differences in degree of care using c-TUG, the differences in physical function in elderly people with mild disequilibrium receiving different degrees of care can show a decline that differs from falls and age-related changes. Also, by evaluating c-TUG in the non-dominant hand, the possibility of grasping deterioration in subjects in Care Needs Category 2 can be considered.

In frail elderly people, there are reports[16] that the tendency to fall is higher for persons who have experienced a decline in performance function as opposed to those with a fall history. c-TUG can evaluate the attention span, as a result of the ability to avoid spilling water from the cup, as well as evaluate the performance function needed to enforce TUG while holding a cup. It is also possible that c-TUG may predict fall risk in elderly people with mild disequilibrium.

In this study, although examined functionality in the elderly using TUG which focuses on mobility via a physical function assessment, it is not clear how this test relates to other indicators such as balance and muscular strength. It is important to compare and examine elderly people who do not fall routinely in their lifestyle and as a function of their Care Needs.

This study was limited by the relatively small number of study subjects and short observation period for the study. In the future, I think it will be necessary to increase the number of subjects and follow their progress over a longer time period.

By evaluating physical function in the elderly with mild disequilibrium using TUG, it is possible to evaluate mobility in those with both mild and progressive disequilibrium. Particularly, with respect to performing c-TUG in the non-dominant hands, an evaluation reflecting the differences in degree of care could be used. It is possible that not only simple movement operations, but also a combination of complex actions and training may be useful physical therapy methods in elderly people with mild disequilibrium.

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The author has no conflict of interest to disclose in connection with this thesis.

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Original Article

Effects of dual-task complexity on finger movement frequency control and accuracy of a visual number counting task

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Abstract. [Purpose] Dual tasking is defined as performing two tasks concurrently. This study aims to quantify the effects of dual-task complexity on the movement frequency that relies on an internal pacemaker and feedback and the accuracy of a visual number counting task. [Subjects and Methods] Twenty right-handed, healthy volunteers participated in this study. They performed one single task and two dual tasks: simple and complex. The single task involved a self-paced tapping task in which the participants extended their right index finger at a 5-second interval. In the dual task, the participants performed the motor task and a visual number counting task simultaneously. [Results] The average time and coefficient of variation of the movement frequency in complex dual tasks were significantly shorter and more variable than those in the single task. [Conclusion] In the complex dual-task condition, high complexity of information processing led to an involuntary increase in the finger tapping movement frequency (hastening) and an increase in the variability of the inter-response interval.
Key Words: hastening, movement frequency, dual task

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1. INTRODUCTION

Humans commonly perform multiple tasks simultaneously (multitasking) in our daily life; walking and using the cell phone at the same time is one example of dual tasking[1]. However, falls or accidental injuries associated with multitasking have been increasing[2]. The use of cell phones in motor vehicles can increase the risk of collision when the driver is distracted for a brief period while attending a call[3]. Dual-task interference or cost has been found to influence the result of the tasks performed in the previous studies[2,3]. Dual-task interference or cost is the deterioration in the performance of one or both individual tasks that are performed concurrently. The following theories explain dual-task interference in humans: capacity-sharing[4], cross-talk[5], and bottleneck[6] theories. However, the mechanisms underlying the dual-task interference are still unclear.

Movement frequency such as the movement timing or inter-response or -trial interval is a component of movement. An increase in the movement frequency under dual-task conditions has been reported[7,8]; this

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phenomenon is called "hastening". It may be an expression of re-automated locomotor control when a higher-order cognitive processing capacity can no longer be allocated to the movements because of the demands of the cognitive task[8]. In these two studies[7,8], the movement was externally paced. In dual-task conditions of daily life, however, both externally and internally paced movements exist. Moreover, feedback of the movement can be made available for the person performing a task, such as in rehabilitation intervention. The relation between the complexity of dual task and the movement frequency that relies on an internal pacemaker or feedback has not been sufficiently investigated.

This study, therefore, aims to quantify the effects of dual-task complexities on the movement frequency that relies on an internal pacemaker and feedback and the accuracy of a visual number counting task. The dual-task interference in this task was assessed on the basis of the frequency of finger tapping and the accuracy of a visual number counting task.

2. SUBJECTS AND METHODS

Twenty right-handed, healthy volunteers (6 females; 14 males; average age ± standard deviation (SD) = 20.25 ± 0.85 years; range: 19–22 years) participated in the study. Handedness was assessed by the Edinburgh Handedness Inventory[9]. This study was approved by the institutional ethics committee of the International University of Health and Welfare (approval No. 16-Io-198). Written informed consent for the study was obtained from all participants.

The participants performed one single task and two dual tasks: simple and complex. The single task is a motor task that involves self-paced tapping with the participants' extended right index finger at a 5-second interval. The intervals were displayed on a monitor as feedback to the participants. In the dual task, the participants performed the motor task and a visual number counting task simultaneously. For the visual number counting task, a random series of numbers 1–9 was presented on a screen and the participants were required to identify the number of times a specified target number appeared. The numbers were presented at an irregular interval of 1–2 second. In the simple dual task, the participants were asked to count the number of "7" appearing amongst a random series of predominantly distractor numbers. In the complex dual task, the participants were asked to count the number of "3" and "7". Each task contained three blocks with 30 trials of 5-seconds intervals. The paradigm is similar to that employed in previous studies[8,10–13]. For the visual number counting task, the X-type Continuous Performance Test in Clinical Assessment for Attention (Japan Society for Higher Brain Dysfunction, Tokyo, Japan) was used. The participants practiced the motor task before the first recording task, and they were briefed about the method to execute the dual task.

Each participant was seated in a comfortable chair 60–70 cm away from a digital computer monitor and their right and left forearms were placed on a table. An electrode of surface electromyography (EMG; DL-141, S&ME, Tokyo, Japan) was placed on the right extensor digitorum muscle of the index finger to determine movement onset. The recorded data were sampled at a rate of 1,000 Hz and analyzed using a multi-analyzer system (Medical Try System, Tokyo, Japan). An EMG artifact was defined as EMG signal at less than 3-second or more than 7-second interval and excluded from an analysis.

The frequency of the participants' finger tapping in the motor task was quantified by considering the average time (AV) and coefficient of variation (CV) between movement onsets for each experimental task condition. EMG artifact was excluded from the analysis. In the visual number counting task, the accuracy of the number of target numbers was measured in each run. For the motor frequency variables, a repeated-measures ANOVA was used for the single task as well as the simple and complex dual tasks. The accuracies of the visual number counting tasks under the simple and complex dual-task conditions were compared using a paired t-test. All statistical analyses were performed in SPSS23 software (IBM Corporation, NY, USA) with the significance level set at $p < 0.05$.

3. RESULTS

Fig. 1 and Fig. 2 show the AV and CV of the movement frequency as a function of the task condition: single task, simple dual task, and complex dual task. The AV and CV show the main effect of the task condition (AV: $F(2,38) = 8.33$, $p < 0.01$), CV: $F(2,38) = 6.21$, $p < 0.01$). Bonferroni post-hoc comparisons of the AV and CV for the three tasks show the following. The AV of the movement frequency in the complex dual task (4.84 ± 0.29) was significantly shorter than that in the single task (5.02 ± 0.14, $p < 0.01$). The simple dual task (4.95 ± 0.22) did not differ significantly from the single task ($p = 0.16$) and the complex dual task ($p = 0.09$). The CV of the movement frequency in the complex dual task (0.97 ± 0.34) was significantly more variable than that in the single task (0.76 ± 0.19, $p = 0.02$). The simple dual task (0.84 ± 0.22) did not differ significantly from the single task ($p = 0.35$) and the complex dual task ($p = 0.11$).

Fig. 3 shows the accuracy of the visual number counting tasks in both the simple and complex dual-task conditions. The accuracy was not significantly affected in both conditions ($t(19) = 1.43$, $p = 0.17$, simple: 94.11 ± 4.64, complex: 92.42 ± 4.13).

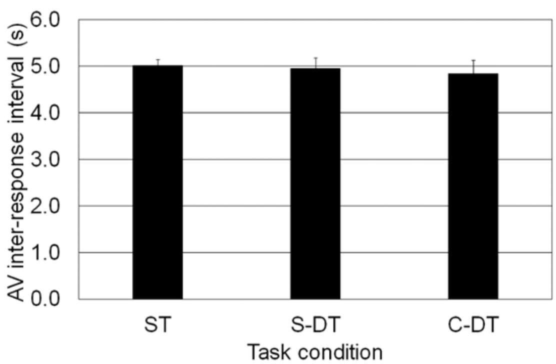

Fig. 1. Average time (AV) movement frequency of the self-paced tapping task.
The error bars indicate the standard error of the mean. ST, single task; S-DT, simple dual task; C-DT, complex dual task.

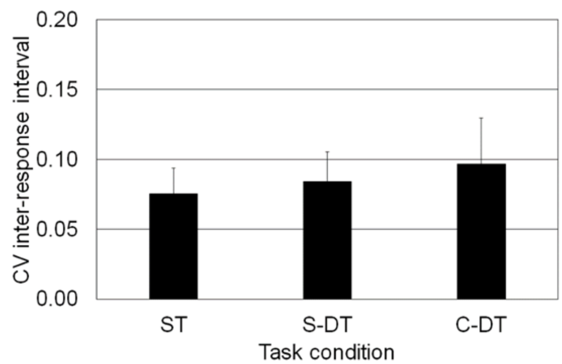

Fig. 2. Coefficient of variation (CV) movement frequency of the self-paced tapping task.
The error bars indicate the standard error of the mean. ST, single task; S-DT, simple dual task; C-DT, complex dual task.

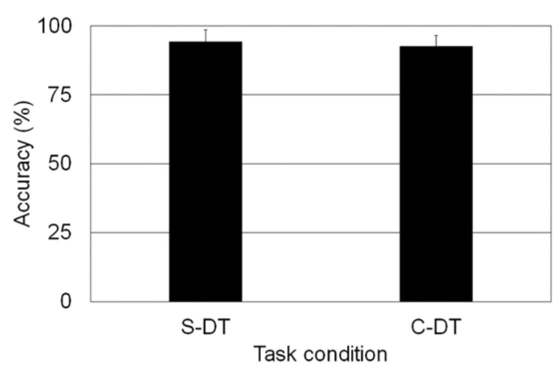

Fig. 3. Accuracy of the visual number counting task performance in the simple (S-DT) and complex dual task (C-DT).
The error bars indicate the standard error of the mean.

4. DISCUSSION

To our knowledge, this is the first investigation of the effects of dual-task complexity on the finger tapping frequency and accuracy of a visual number counting task. Our results indicate that high complexity of information processing in the complex dual-task condition led to an involuntary hastening of the finger tapping (increase in the finger tapping movement frequency). Furthermore, the variability in the inter-response interval increased in the complex dual-task condition.

In this study, we observed an increase in the finger tapping movement frequency in the complex dual task. This result is similar to those of the following studies on dual tasking. Van Impe et al. (2011) showed that both old and young participants increased the frequency of drawing movements under a dual-task condition compared to that under a single-task condition[7)]. Johannsen et al. (2013) observed an increase in the movement paced by a metronome frequency with increasing n-back difficulty[8)]. We suggest that hastening of the finger tapping depends on an internal pacemaker and feedback as well as an external stimulus under a dual-task condition. However, we cannot judge which factors (an internal pacemaker or feedback) influence the results. Recently, Langhanns et al. (2018) explained the hastening effect on the basis of three essential assumptions: (i) there exist two different control regimes, an automatic and a cognitively controlled mode of operation; (ii) the processing of a cognitive secondary task interferes with the cognitive motor control processes; and (iii) the automatic process controls the movement less strictly, that is, corrects errors less frequently and extensively[14)]. We believe that these assumptions may be needed to better understand the results of this study.

The accuracy of the visual number counting tasks did not significantly differ in the simple and complex dual-task conditions. However, the AV and CV of the movement frequency in the complex dual task were significantly shorter and more variable than those in the single task. Moreover, in terms of both AV and CV, the simple dual task did not differ from the single task and the complex dual task. The accuracy of the task was constant but the movement frequency was affected as the task complexity increased. This suggests that the amount of effort required for performing the tasks differs even if the rates of accurate answers are equal or similar. The effort amount may include the attention required or the working memory as well as motor capacities.

In the present study, the participants extended their right index finger at a interval of 5 second. These intervals were displayed on a monitor as feedback for them. This methodology using feedback has often been used in rehabilitation such as physiotherapy or occupational therapy intervention in order to increase the motivation and will of a patient to perform a task. We believe that the participants could execute the tasks while continuously correcting and modifying the movement frequency by maintaining high motivation and attention. This helped the participants in maintaining a performance with high abilities during the experiment.

In this study, the dual-task interference was assessed on the basis of the finger tapping frequency and the accuracy of the visual number counting task, which include the cognitive-motor dual task. Plummer et al. (2013) proposed a classification framework for patterns of cognitive-motor interference based on changes in the performance of each task in the dual-task condition relative to the single-task performance[15)]. People commonly perform various types of multitasking in their daily life. The processing speeds and amounts for the individual tasks that are performed concurrently differ. Therefore, when the complexity of a task increases, a sufficient performance level cannot be maintained throughout the task, as observed in daily life.

It is worthy to compare the results for people with specific neurological diseases, elderly, and children. Van Impe et al.'s (2011) study involved young and older adult participants[7)]. Different patterns of increased or decreased activation of task-specific or non-specific neuronal areas have been reported[16)]. We also strongly recommend further studies to better understand the neurological basis of dual-task interference using neuroimaging techniques (functional magnetic resonance imaging, functional near-infrared spectroscopy, or positron emission tomography) or neurophysiological instruments (event-related potential, electroencephalography, or magnetoencephalography).

Funding and Conflict of interest

Funding information is not available. The authors report no conflicts of interest for the submission of this manuscript.

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