Introduction

During the course of our daily activities, we are able to pay general attention to our surroundings to find target objects while avoiding obstacles. At the same time, we are also able to continue performing target activities without being distracted more than necessary by things in our surroundings that are not relevant to the task at hand. These functions are called attentional functions, and they are essential to safely and smoothly perform activities of daily living (ADL) and activities parallel to daily living (APDL). A range of different symptoms is observed in patients with impairments in these attentional functions. Thus, the same patient may show different symptoms depending on the environment in which he or she is placed. Moreover, medical professionals do not fully understand this pathology. The conventional methods for clinical evaluation of attention deficit use written neuropsychological screening tests and combine them with behavioral observations. How-

Development of a Method that Uses Reaction Time to Evaluate Attention Deficit Associated with Changes in Dynamic Visual Stimuli

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Abstract: Attentional functions are essential to safely and smoothly perform activities of daily living. A range of different symptoms is observed in patients with impairments of attentional functions. Thus, the same patient may show differences in symptoms depending on the environment in which he or she is situated. In this study, we sought a means to characterize attention deficit with higher sensitivity than conventional neuropsychological tests, such as the Trail Making Test (TMT) and the Clinical Assessment for Attention (CAT), do. We developed two reaction time (RT) tasks: a simple task and a speed change task. We then enrolled 10 right-handed healthy older adults with no history of brain injury and 10 right-handed patients with stroke to perform the RT tasks. In addition, the stroke group underwent the TMT, the CAT and behavioral observation by an occupational therapist to identify symptoms characteristic of attention deficits. Results for findings of attention deficits on standard neuropsychological tests had a sensitivity of 25% in static situations (e.g., desk activities) and 33% in dynamic situations (e.g., walking or moving). In contrast, when applied to static situations, the simple and speed change RT tasks achieved a sensitivity of 75% and 100%, respectively. The sensitivity in dynamic situations was 33% to 44% for the simple task and 100% for the speed change task. These results suggest that the RT tasks developed in this study are capable of identifying attentional deficits in patients with stroke, and may be more sensitive than neuropsychological testing combined with behavioral observations.

Keywords: Assessment, Attention, Reaction time methods, Visual search

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ever, it has been reported that some patients who score higher than the standard for impairment on these written tests, nevertheless exhibit attention deficits in real-life situations such as falling while walking, getting into automobile accidents, etc [1]. Therefore, it has become clear that in some patients a difference exists between their results on existing clinical tests and the actual symptoms encountered in daily living.

Towards better diagnosing and understanding attentional deficits, there are prominent examples of scorable behavioral observation evaluation methods, including the Ponsford and Kinsella’s Attentional Rating Scale (ARS), developed by Ponsford and Kinsella (1991) [2], and the Moss Attention Rating Scale (MARS), developed by Whyte, Hart, Ellis, and Malec (2003, 2008) [3, 4] being used in combination with written clinical tests of attention. However, evaluation by behavioral observation depends greatly on the experience of the evaluator, and it is difficult to eliminate the possibility that an occupational therapist with little experience might overlook clinical findings of attention deficit. Furthermore, evaluation results for the same patient on the same day may differ depending on the environment in which the patient is observed; thus, the effect of environmental dependence must also be studied.

In the fields of psychology and brain science, attention is classified from the perspective of visual information processing, and efforts to understand its mechanisms are underway. These classifications include stimulus-driven (bottom-up) attention and voluntary (top-down) attention [5]. The sequence in which bottom-up attention is processed is believed to change based on the salience of visual stimuli, and this fact is considered to be extremely important for avoiding danger in situations where the surrounding environment is constantly changing, as it is in real, everyday life [6]. When the characteristics of the existing tests are examined according to this classification of attention, it is clear that the tests include many elements of top-down attention, in which cognitive processing is performed by focusing attention on a visual target such as letters or figures printed on a sheet of paper. A small percentage of the elements in these tests also involve aspects of bottom-up attention, as the salience of changing stimuli is continually processed. We postulate that these characteristics are one reason why the results of the existing tests often do not agree with attention deficit occurring in daily life.

Therefore, we endeavored to develop an attention deficit evaluation method based on reaction time (RT) as a means of understanding the mechanism of attentional function from the standpoint of visual information processing [7]. In our previous research, two types of tasks in which the placement or flashing pattern of displayed visual stimuli were changed were used together with simple, conventional RT tasks. The results of the RT tasks were then compared with the attention deficit findings from daily life and conventional neuropsychological tests. The results showed that the RT tasks reflected a subject’s attention deficit findings with higher sensitivity than the conventional neuropsychological tests, but could not detect attention deficit in subjects suspected of having mild disability [7]. This is believed to be because the two RT tasks that were used only utilized changes in the visual stimuli characteristic of brightness and therefore did not completely reflect the previously described bottom-up attention elements. In a study by Viviani and Aymoz (2001) that used reaction time (RT) to assess the difficulty of perceiving changes in the elements of shape, color, and movement, it was discovered that movement changes were difficult to perceive [8].

In light of the study by Viviani and Aymoz (2001) [8] and in an effort to develop an evaluation method capable of appropriately reflecting attention deficit, we developed an RT task in which the speed of displayed visual stimuli changed. We then studied how the results of this task related to attention deficit findings.

**Subjects and Methods**

**Subjects**

The subjects were ten right-handed healthy older adults with no history of brain injury (mean age, 71.3 ± 6.1 years; 6 males, 4 females) and ten right-handed patients with stroke (mean age, 70.4 ± 6.4 years; 7 men, 3 women). Both the healthy older adults and the stroke patients were selected only if they had no overt decline in cognitive function, with a Mini-Mental State Examination (MMSE) score of 24 points or higher. Additional exclusion criteria among the stroke patients were: motor function impairment severe enough to interfere either with carrying out the touch sensor operations or performing neurological tests using the arms, hands, and fingers of the unaffected side of their body (at or below the standard value in the Simple Test for Evaluating Hand Function [STEF]); observation of hemispatial neglect; a total score below the standard value on either a conventional test or a behavioral test listed in the Japanese version of the Behavioral Inattention Test; and visual field impairment. A detailed profile of the patients is shown in Table 1.

**Task Methods**

**Procedure.** The subjects were asked to perform two types of RT tasks (a simple reaction task and a speed change task). In addition, the stroke patients were asked...
In the simple reaction task, a black background screen was displayed at random intervals of time for a period of 3 to 5 sec, and afterward, a target stimulus (red circle with a diameter of 1 degree in visual angle) was displayed in the center of the screen. The amount of time from when the target stimulus was displayed until the subject’s finger was released from the touch sensor was recorded. Note that if the subject did not react within 1.5 sec after the target stimulus was displayed, the present trial was discontinued. This trial was run 24 times.

In the speed change task, after a black background screen was displayed, 36 red circles with a diameter of 1 degree in visual angle appeared on the screen (the screen had a width with a visual angle of 45 degrees and a height with a visual angle of 26 degrees). All of the red circles moved at a speed of a visual angle of 10 degrees in a randomly determined direction in the up or down and left or right directions (Fig. 1B). After 1.0 or 1.5 sec, the movement of one of the 36 red circles (the target) slowed by 5 degrees every second. As soon as the subject noticed the target, he or she would respond with the sensor. The time from when movement speed of the single target red circle began to change until the patient responded was recorded (Fig. 1A). However, in order to measure the accuracy of the responses, trial runs in which the movement speed did not change were randomly included, and the subject was instructed not to respond in these cases. If the movement speed changed and the subject did not respond within 3.5 sec, the subject was considered to have overlooked the target, and if the movement speed did not change, the run was finished after 3.5 sec. There were 36 trials in total, 24 in which the movement speed of the target changed, and 12 in which the movement speed did not change. The 36 red circles are arranged one by one in randomly predetermined positions in each area obtained by dividing the display into 36 equal parts (4 × 9). Twenty-four red circles arranged in the central areas were randomly selected once for each as a moving target whose direction
was also determined randomly but the total number of each direction was equally set. Therefore, there was no spatially biased throughout the experiment.

**Analytical methods.** The mean and standard deviation (SD) of the number of trials that the subject completed successfully without overlooking the target were calculated for each task and used as the results of the RT tasks. In addition, the number of speed change task trials that each subject could not complete were quantified. Then three values, the mean + 1.5 x SD, the mean + 2 x SD, and the mean + 2.5 x SD, were calculated as candidates for standard values reflective of the results of the healthy elderly individuals, and a determination was made as to whether the reaction times of the stroke patients were slower than these standard values. The validity of the three candidates is discussed according to the sensitivity and specificity for attention deficits of the patients.

For the TMT, we referred to the mean value measured in 29 healthy older adults (68 to 94 years old) by Sugimoto, et al. (2014) [10] in which the mean ± SD was 174.0 ± 69.3 sec for TMT-A and 320.8 ± 152.4 sec for TMT-B. The mean ±1.5 x SD, the mean ± 2 x SD, and the mean ± 2.5 x SD were similar to the RT task results; the specific results for TMT-A were 278.0 sec, 312.6 sec, and 347.3 sec, respectively, and the results for TMT-B were 549.4 sec, 625.6 sec, and 701.8 sec, respectively. These values were adopted as standard values of the TMT and were used to judge the existence of attention deficit.

For the visual cancellation task in CAT, standard values for the percentage of correct responses for subjects in their sixties and seventies are 92.9% and 91.7%, respectively. There was no standard set in the CAT for subjects in their eighties, so we used an accuracy rate of 91.7% as the standard value for persons in their seventies and older.

The observational evaluation was a qualitative evaluation of whether findings of attention deficit were shown in static situations, such as during desk activities, or whether attention deficit was shown in dynamic situations, such as when walking or operating a wheelchair.

Because the stroke patients performed the RT task and neuropsychological tests with their dominant hand or the hand on the unaffected side of their body and they had scored values higher than the standard for their age group in the STEF, their upper limb function was judged to have no effect on the results of any of the tasks. Thus,
no corrections for the results of the tasks and the tests were implemented. All of the results for the RT tasks, the pre-existing neuropsychological tests, the TMT, and the visual cancellation task, were compared with the results from the behavioral observations, and sensitivity and specificity were calculated.

Ethical approval

This study was approved through an ethical review by the Ethics Committee of Sapporo Medical University. In addition, this study was performed in compliance with the Declaration of Helsinki and placed careful attention on protecting the privacy and human rights of the subjects.

When data were measured, the subjects were provided with oral and written explanations of the study purpose, methods, procedures, subjects, anticipated risks, matters related to the human rights of the subjects, the rights of the subjects in the event that they did not provide consent, etc. After this information was provided, the signatures of the individuals who consented to the study were obtained, and only individuals from whom informed consent was obtained were used as subjects in this study. The subjects were also told that they could withdraw consent to participate in the study if they requested such during the study or after the study.

Results

RT tasks

The results of RT task of the healthy older subjects are shown in Table 2. The overall reaction time for the healthy older subjects was 250.1 ± 33.7 msec in the simple reaction task and 479.1 ± 40.9 msec in the speed change task. There were 2 healthy older subjects who overlooked the target once in the speed change task.

When convenient standard values were calculated from these results, the mean + 1.5 x SD, the mean + 2 x SD, and the mean + 2.5 x SD in the simple reaction task were 300.7 msec, 317.4 msec, and 334.4 msec, respectively. The mean + 1.5 x SD, the mean + 2 x SD, and the mean + 2.5 x SD in the speed change task were 540.5 msec, 560.9 msec, and 581.4 msec, respectively.

The results of RT tasks of the stroke subjects are shown in Table 2. In the simple reaction task, the reaction time was delayed in patients 1, 2, 3, 6, and 10 when the standard value was considered to be the mean + 1.5 x SD. When the standard value was considered to be the mean + 2 x SD or + 2.5 x SD, the reaction time was delayed in patients 1, 2, and 3.

In the speed change task, the reaction time was delayed in all patients when the standard value was considered to be the mean + 1.5 x SD. When the standard value was considered to be the mean + 2 x SD or + 2.5 x SD, the reaction time was delayed in patients 1, 2, and 3.

The results of the behavioral evaluation are shown in Table 2. The overall reaction time for the healthy older subjects was 250.1 ± 33.7 msec in the simple reaction task and 479.1 ± 40.9 msec in the speed change task. There were 2 healthy older subjects who overlooked the target once in the speed change task.

When convenient standard values were calculated from these results, the mean + 1.5 x SD, the mean + 2 x SD, and the mean + 2.5 x SD in the simple reaction task were 300.7 msec, 317.4 msec, and 334.4 msec, respectively. The mean + 1.5 x SD, the mean + 2 x SD, and the mean + 2.5 x SD in the speed change task were 540.5 msec, 560.9 msec, and 581.4 msec, respectively.

The results of the behavioral evaluation are shown in Table 2. In the simple reaction task, the reaction time was delayed in patients 1, 2, 3, 6, and 10 when the standard value was considered to be the mean + 1.5 x SD. When the standard value was considered to be the mean + 2 x SD or + 2.5 x SD, the reaction time was delayed in patients 1, 2, and 3.

In the speed change task, the reaction time was delayed in all patients when the standard value was considered to be the mean + 1.5 x SD. When the standard value was considered to be the mean + 2 x SD or + 2.5 x SD, the reaction time was delayed in patients 1, 2, and 3.

The results of the TMT and the visual cancellation task are shown in Table 3. No matter which standard value was used, none of the subjects showed findings of attention deficit in the TMT. In the visual cancellation task, patients 1, 4, and 9 showed findings of attention deficit.

Neuropsychological tests

The results of the TMT and the visual cancellation task are shown in Table 3. No matter which standard value was used, none of the subjects showed findings of attention deficit in the TMT. In the visual cancellation task, patients 1, 4, and 9 showed findings of attention deficit.

Behavioral observations

The results of the behavioral evaluation are shown in Table 4. In static situations, such as during desk activities, 3 of 10 patients (patients 1, 2, and 3) showed overt attention deficit findings. Note that patient 8 showed findings suggestive of attention deficit. In addition, in dynamic situations in which visual information changes, such as operating a wheel chair, walking, etc., 9 patients (all patients except patient 10) showed attention deficit findings.

Table 2. Results of the RT task

| Subjects         | Simple RT | Speed change RT |
|------------------|-----------|-----------------|
|                  | M (msec)  | M (msec)        | Omission |
| Healthy elderly  |           |                 |          |
| 1                | 272.8     | 484.6           | 0        |
| 2                | 322.1     | 498.2           | 0        |
| 3                | 252.0     | 402.8           | 0        |
| 4                | 258.1     | 432.3           | 0        |
| 5                | 213.8     | 501.4           | 1        |
| 6                | 198.8     | 447.3           | 1        |
| 7                | 231.1     | 462.4           | 0        |
| 8                | 232.2     | 539.7           | 1        |
| 9                | 240.8     | 490.5           | 0        |
| 10               | 279.3     | 531.7           | 6        |
| mean             | 250.1 ± 33.7 | 479.1 ± 40.9 |          |
| Stroke patients  |           |                 |          |
| 1                | 349.4     | 1879.7          | 7        |
| 2                | 438.7     | 1326.1          | 0        |
| 3                | 365.9     | 660.1           | 0        |
| 4                | 215.5     | 802.6           | 1        |
| 5                | 226.4     | 606.0           | 0        |
| 6                | 312.6     | 595.5           | 3        |
| 7                | 211.5     | 1024.7          | 1        |
| 8                | 287.0     | 843.8           | 0        |
| 9                | 281.7     | 814.4           | 0        |
| 10               | 302.1     | 548.4           | 0        |
| mean             | 299.1 ± 68.6 | 910.1 ± 391.9 |          |

M (msec), Omission (number of incidences).
In order to verify that the RT tasks developed in this study reflected the attention deficit findings from the behavioral observations better than the existing neuropsychological tests, the sensitivity and specificity of the judgments of attention deficit findings in the RT tasks, TMT, and visual cancellation test were calculated with respect to the attention deficit findings from the behavioral observations of a total of 20 healthy older subjects and stroke patients in static and dynamic situations. The results are shown in Table 5.

In the TMT-A, at all of the standard values, the sensitivity and specificity were 0% and 100%, respectively, for attention deficit findings in static situations, and 0% and 100%, respectively, in dynamic situations.

In static situations in the simple reaction task, sensitivity and specificity were 75% and 81%, respectively, when the standard value was the mean + 1.5 x SD; 75% and 94%, respectively, when the standard value was the mean + 2 x SD; and 75% and 100%, respectively, when the standard value was the mean + 2.5 x SD.

In dynamic situations in the simple reaction task, sensitivity and specificity were 44% and 82%, respectively, when the standard value was the mean + 1.5 x SD; 33% and 91%, respectively, when the standard value was the mean + 2 x SD; and 33% and 100%, respectively, when the standard value was the mean + 2.5 x SD.

In static situations in the speed change task, sensitivity and specificity were 100% and 63%, respectively, when the standard value was the mean + 1.5 x SD; 100% and 69%, respectively, when the standard value was the mean + 2 x SD; and 100% and 69%, respectively, when the standard value was the mean + 2.5 x SD.

In dynamic situations in the speed change task, sensitivity and specificity were 100% and 91%, respectively, when the standard value was the mean + 1.5 x SD; 100% and 100%, respectively, when the standard value was the mean + 2 x SD; and 100% and 100%, respectively, when the standard value was the mean + 2.5 x SD.

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**Table 3. Results of neuropsychological tests of patients with stroke**

| Case | Neuropsychological test | TMT-A | TMT-B | Cancellation task |
|------|-------------------------|-------|-------|-------------------|
| 1    | TMT-A                  | 187   | 201   | 86.8*             |
| 2    | TMT-B                  | 107   | 153   | 97.4              |
| 3    | Cancellation task      | 92    | 216   | 98.2              |
| 4    | TMT-A                  | 126   | 194   | 91.2*             |
| 5    | TMT-B                  | 87    | 139   | 96.5              |
| 6    | Cancellation task      | 265   | 347   | 99.1              |
| 7    | TMT-B                  | 127   | 321   | 95.6              |
| 8    | Cancellation task      | 184   | 267   | 94.7              |
| 9    | TMT-A                  | 206   | 372   | 92.1*             |
| 10   | TMT-B                  | 170   | 196   | 94.7              |

TMT-A Trail Making Test part A (sec), TMT-B Trail Making Test part B (sec), Cancellation task: Visual cancellation task (rate of cancellation %), *outside of normal range.

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**Table 4. Qualitative clinical observations by occupational therapists**

| Case | Static scene | Dynamic scene |
|------|--------------|---------------|
| 1    | Talkativeness, Distractibility, Restless | Field of view is narrow when moving. Sense of distance is abnormal. |
| 2    | Overlook small part caused by lack of confirmation during handwork. | Hit surroundings during wheelchair operation. |
| 3    | A little delay in the start of the action. | The sense of distance between the object being small when walking. Action can be modified to be careful. |
| 4    | No particular problem | Cannot find a person when walking. Possible to notice defects immediately in the voice over. |
| 5    | No particular problem | Rarely, not aware of the objects on the floor. |
| 6    | No particular problem | Sense of distance is abnormal during walking. Never hit surroundings. |
| 7    | No particular problem | Sometimes hit surroundings. |
| 8    | Sometimes mistaken for voice over increases during handwork. | Sense of distance is abnormal. Almost always hit surroundings. |
| 9    | No particular problem | Do not try to avoid obstacles even if there is a person or an object, delay in avoiding. |
| 10   | No particular problem | No particular problem |
Discussion

Attention deficit findings of the patients and results of existing neuropsychological tests

The results of the existing neuropsychological tests used in this study showed that the TMT was unable to detect attention deficit findings and that the visual cancellation task was able to detect attention deficit findings. However, the sensitivity was 25% in static situations and 33% in dynamic situations, which are very low values. These results support the previous studies [1] that reported a difference between the results of the neuropsychological tests and symptoms observed in situations such as driving a vehicle or walking. The reason for this is considered to be that the neuropsychological tests involve few changes in visual stimuli and thus are low-salience tasks with narrow display ranges. This suggested that the existing neuropsychological tests alone did not completely reflect the clinical attention deficit findings in either static or dynamic environments.

Attention deficit findings of the patients and the results of RT tasks

In the RT tasks used in this study, the sensitivity toward attention deficit findings in static situations was 75% for simple responses and 100% for the speed change task, both of which were high values. In addition, the sensitivity in dynamic situations was 33% to 44% for simple responses and 100% for the speed change task. The RT tasks used in this study did not contain very many cognitive elements such as letters and numbers, rather they asked subjects to find and respond to targets in an environment where the brightness and speed of visual stimuli changed. Therefore, these tasks were considered to be capable of reflecting attention deficit mainly in dynamic environments, and the sensitivity of the speed change task is considered to support that. We posit that the low sensitivity of the simple reaction task, which is in contrast to the speed change task, may owe to the simple reaction task using only changes in the simple flashing of visual stimuli. This implies that the amount of change of dynamic visual stimuli may have greatly affected the results. Therefore, judging from the sensitivity and specificity of the behavioral observations, a more appropriate evaluation is considered to be one that combines a simple reaction task, in which the change in visual stimuli is relatively small and reflects attention deficit in static situations, with a speed change test, in which the change in visual stimuli is large and reflects attention deficit in dynamic situations.

Standard values

Though there have been a lot of studies aimed at evaluating attention disorders and clarifying their characteristics using RT tasks, no standard value has been clearly determined so far [1, 11]. This is why three candidates for standard values reflective of the results of the healthy older adults are introduced in this study. As a result, the neuropsychological tests in both static and dynamic scenes and the simple reaction task in dynamic scene showed low sensitivity and high specificity for three candidates for standard values, while the simple reaction task in static scene and speed change task in both scenes showed high sensitivity and high specificity for them. From these results, it may be reasonable to set any of the three reference values as the standard value for the RT tasks but more data collection is necessary to conclude it.

Limitation of research and Future outlook

Since the observation scene and activities were limited in this research, only a part of daily life of attention disorder patient could be examined. Previous studies that used RT tasks also contained little information about setting standard values; thus, we think that the establishment of standard values is important in future studies. In addition, the functional structures inside the brain responsible for processing the speed of movement of visual stimuli have recently been discovered [12–14]. If this new information can be exploited to perform

| Scene | Reference Value | Neuropsychological test | RT tasks |
|-------|----------------|-------------------------|----------|
|       |                | TMT-A | TMT-B | Cancellation task | Simple RT | Speed change RT |
| Static| M + 1.5SD      | 0/100 | 0/100 | 25/88 | 75/81 | 100/63 |
|       | M + 2.0SD      | 0/100 | 0/100 |        | 75/94 | 100/69 |
|       | M + 2.5SD      | 0/100 | 0/100 |        | 75/100| 100/69 |
| Dynamic| M + 1.5SD     | 0/100 | 0/100 | 33/100 | 44/82 | 100/91 |
|       | M + 2.0SD      | 0/100 | 0/100 |        | 33/91 | 100/100|
|       | M + 2.5SD      | 0/100 | 0/100 |        | 33/100| 100/100|

The value in the table, Sensitivity (%)/Specificity (%).
a more functionally segmented clinical evaluation of attention deficit, we believe that more highly individualized occupational therapy could be provided. However, the behavioral observations in our study had many qualitative elements and did not contain a quantitative method. Therefore, they did not allow for such segmentation. In the future, we also hope to study ways in which behavioral observations of attention deficit can be performed in a more quantitative manner. We would also like to enroll a larger number of subjects in order to study the step-wise correlations between RT tasks and various symptoms and the relationship with actual real life activities.

Conflicts of interest statement

The authors have no conflicts of interest relevant to this article.

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