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Original Article

Assessment of finger motor skills in individuals with mild cognitive impairment and patients with Alzheimer's disease: Relationship between finger-to-thumb tapping and cognitive function

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ABSTRACT
Suzumura S, Osawa A, Nagahama T, Kondo I, Sano Y, Kandori A. Assessment of finger motor skills in individuals with mild cognitive impairment and patients with Alzheimer's disease: Relationship between finger-to-thumb tapping and cognitive function. Jpn J Compr Rehabil Sci 2016; 7: 19−28.
Objective: Decreased finger dexterity can impede a person's daily activities. The present study examined finger dexterity in individuals with mild cognitive impairment (MCI) and patients with Alzheimer's disease (AD) compared with healthy older adults using a magnetic sensing finger tapping device (UB-1).
Methods: Finger-to-thumb tapping tasks were carried out by 23 patients who were diagnosed with AD or MCI at the authors' hospital (AD/MCI group) and 22 members of their families (healthy control group), and measurement parameters were calculated. Mini-Mental State Examination (MMSE) was carried out to assess cognitive function and the association between finger function and the results of MMSE was evaluated. Additionally, the measurement parameters were compared between the AD/MCI group ($n = 14$) and the healthy control group ($n = 13$) after adjusting for age.
Results: A correlation between finger function and MMSE results was observed in five measurement parameters ($r \geq 0.6$). Additionally, in the AD/MCI group, the total traveling distance was shorter compared to that in the healthy control group and rhythm perturbations were observed ($p < 0.05$).
Discussion: In the present study, the AD/MCI group showed decreased finger dexterity, which was also found to be associated with decline in cognitive function. It is suggested that assessment of finger dexterity can be used as an indicator of cognitive function.
Key words: Alzheimer's disease, finger function, dexterity, finger tapping

Introduction

There are approximately 4,620 thousand patients with dementia in Japan today and the number is projected to reach 7 million by 2025 [1]. Thus, the increase in the population with dementia, which has already become a major social issue, is likely to worsen in the future. Against this social background, there has been an increasing interest in dementia and growing social demand for enhanced healthcare for the disease.

Dementia has been defined as a condition that involves higher brain dysfunction, with memory impairment as the core symptom, which is not transient but persists and degenerates over time. However, it has been reported that not only higher brain function but also motor function—fine motor skills, in particular—are impaired in patients with Alzheimer's disease (AD), which accounts for 50% of the total dementia cases [2]. Finger dexterity is believed to influence implementation of self-care and instrumental activities of daily living (IADL). Therefore, knowledge of the degree of impairment of finger dexterity is important in providing rehabilitative care for dementia.

Indicators for quantitatively evaluating motor dexterity include finger tapping tasks [3−5], the Purdue Pegboard Test, and three-dimensional motion analysis of the movements for touching targets. However, motor dexterity testing that involves complicated tasks is prone to the effect of language understanding and memory ability. Additionally, patients with MCI or

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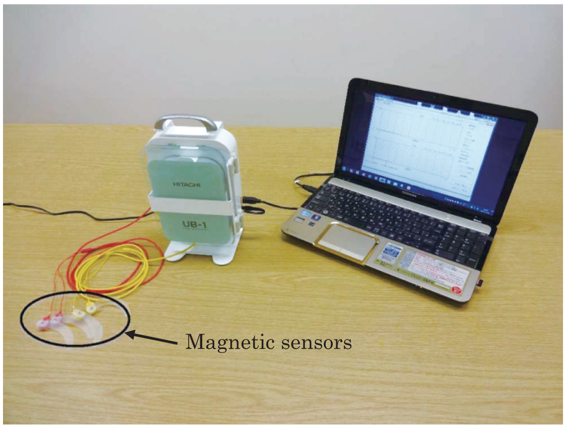


Figure 1. Magnetic sensing finger tapping device (UB-1).
The yellow cable is attached to the thumb and the index finger of the left hand, and the red cable is attached to the thumb and the index finger of the right hand. The main body of the device is connected to a PC, thereby enabling monitoring of the waveforms of finger tapping tasks on the computer.

those with a lack of understanding of the disease do not prefer cognitive function tests such as MMSE. Therefore, finger-to-thumb tapping, which involves easy tasks and requires a shorter time than other tests such as MMSE, is considered to be appropriate for assessing fine motor skills in dementia, particularly in AD. Recently, Hitachi Central Research Laboratory developed a device to measure finger motor function (magnetic sensing finger tapping device) [6], which not only measures the timing of finger taps, but also enables the assessment of finger dexterity including inter-hand coordination and rhythm (Figure 1).

The objectives of the present study were to verify that this magnetic sensing finger tapping device can detect the difference in finger dexterity between patients diagnosed with AD or MCI and healthy older adults, as well as to identify the measurement parameters that improve the statistical power to evaluate progression of AD, by clarifying the relationship between cognitive function and finger dexterity.

Subjects

The study included 23 patients who were diagnosed as having AD or MCI at the Center for Comprehensive Care and Research on Memory Disorders in the authors' hospital (AD/MCI group) and 22 members of their families who have no problem with cognitive function (healthy control group). The 23 subjects in the AD/MCI group and 22 subjects in the healthy control group were all right-handed. The number of subjects presented here is the number of subjects after excluding some individuals by interview sheet (described later). In the AD/MCI group, a total of 2 patients were excluded from the study based on the interview sheet (described later): one with a past medical history of stroke and the other who had been diagnosed with corticobasal degeneration. Additionally, in the healthy control group, a total of 3 individuals were excluded: one with a past medical history of stroke and two others who had been diagnosed with Parkinson's disease. After making these exclusions, the AD/MCI group ($n = 23$) was aged 61−88 years (mean, 76.2 years), while the healthy control group ($n = 22$) was aged 41−82 years (mean, 63.1 years).

Because of the difference in age between the healthy control group and AD/MCI group, age adjustments were applied to choose subjects by matching the individuals based on age. Specifically, we repeated a process of excluding the youngest individual from the healthy control group and the oldest individual from the AD/MCI group until the two groups were balanced on mean age. As a result, a total of 18 individuals were excluded from the AD/MCI group and healthy control group combined, yielding an AD/MCI group consisted of 14 patients (mean age, 72.5±6.1 years) and a healthy control group consisted of 13 individuals (mean age, 71.7±7.9 years) as subjects for analysis and for comparing the finger tapping parameters between the two groups.

The exclusion criteria were patients with difficulty in communication, as well as patients with higher brain dysfunction, apparent movement paralysis, fine motor skill disorder, and psychiatric diseases that may interfere with testing.

All subjects or their families were given sufficient explanation about the importance of the study verbally and in writing in advance, and their agreement to participate in the study as cooperators for the experiment was obtained. The study was carried out with the approval of the ethics committee of the authors' hospital (No. 623-4).

Methods

1. Filling out the interview sheet

The AD/MCI group was asked to fill out the interview sheet to provide background information pertaining to dementia. They also underwent MMSE before measurement of the finger motion was initiated. The healthy control group was also asked to fill out the same interview sheet before performing the finger tapping task so that we could ascertain their past medical history of stroke, presence of fine motor skill disorder, and situation of daily living.

2. Clinical Dementia Rating (CDR)

CDR [7] is a 5-point scale used to assess the severity of dementia based on the scores for each of the 6 domains, i.e. Memory, Orientation, Judgment and Problem-solving, Community Affairs, Home and Hobbies, and Personal Care. The results of the rating are integrated to assess the severity as one of the following stages: normal (CDR 0), suspected dementia (CDR 0.5), mild dementia (CDR 1), moderate dementia (CDR 2), and severe dementia (CDR 3). The patients who had been diagnosed with AD or MCI in the present study were assessed as either of CDR 0.5 (suspected dementia), CDR 1 (mild dementia) or CDR 2 (moderate dementia).

3. Method of measurement

In the measurement using the magnetic sensing finger tapping device, the subject wore the magnetic sensors on the index finger and the thumb and performed the finger-to-thumb tapping task (repetitive index-finger-to-thumb oppositions) (Figure 2). In the finger-to-thumb tapping task, four modes of movement were measured, i.e. a discrete run with the dominant hand, index-thumb tapping in synchrony with a metronome with the dominant hand, bimanual index-thumb tapping in-phase, and bimanual index-thumb tapping anti-phase. In the discrete run with the dominant hand, the subjects performed the index-thumb opposition task with the dominant hand. In the synchronization with a metronome with the dominant hand, they carried out the finger-to-thumb tapping task by executing the index-thumb oppositions with the dominant hand in synchrony with metronome clicks given by a PC. In the in-phase bimanual task, the subjects performed the index-thumb opposition task with both hands simultaneously, whereas in the anti-phase bimanual task, the subjects repeated the index-thumb oppositions with one hand after the other. When the measurements were completed, the magnetic sensing finger tapping device yielded 44 measurement parameters (Table 1). The parameters analyzed in the present study were: total traveling distance (refer to Table 1, No. 2), energy balance (balance between flexing movement and extending movement; refer to Table 1, No. 13), standard deviation of contact duration (dispersion of the times the two fingers were in contact; refer to Table 1, No. 29), standard deviation of inter-tapping interval (rhythm perturbation; refer to Table 1, No. 36), and standard deviation of phase difference (dispersion of inter-hand gaps; refer to Table 1, No. 42). The dispersion of inter-hand gaps is a measurement parameter for the in-phase bimanual task and anti-phase bimanual task. Therefore, this parameter is not applicable to unimanual tasks, i.e. the discrete run with the dominant hand and the finger-to-thumb tapping to a metronome with the dominant hand.

4. Method of data analysis

For data analysis of the finger-to-thumb tapping parameters, the *t*-test was used to compare the differences in performance between the AD/MCI group and healthy control group, in which we adopted the *t*-test that assumes two samples have unequal variances. The association between the measurement parameters described above and the severity of dementia (assessed by MMSE scores) was tested using Spearman's correlation coefficient. Data was consid-

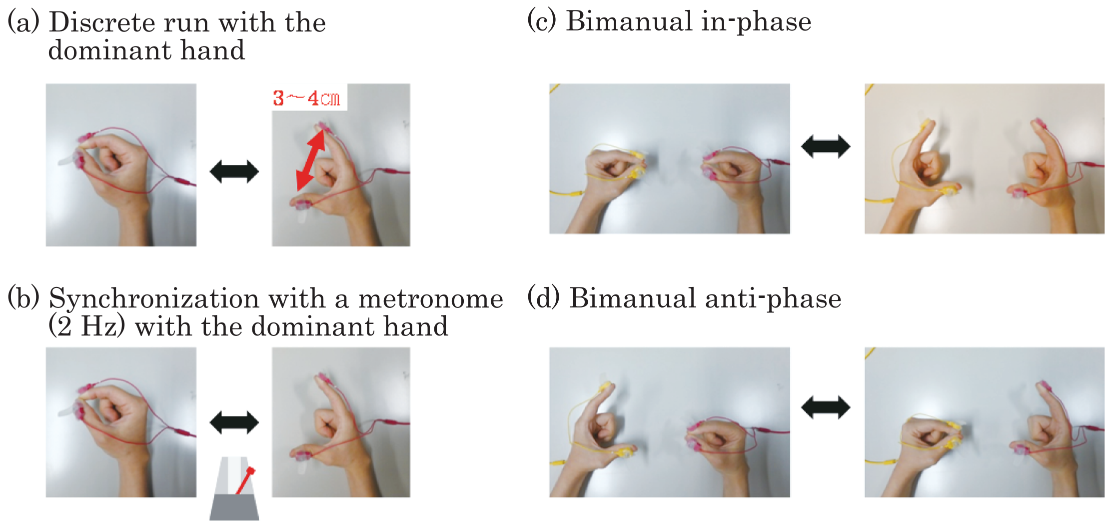


Figure 2. Finger-to-thumb tapping task (Index-Thumb Opposition Task).
(a) Discrete run with the dominant hand: Subjects perform the finger-to-thumb tapping task as rapidly as possible.
(b) Finger-to-thumb tapping to a metronome with the dominant hand: Subjects execute the finger-to-thumb tapping task by touching the index finger to the thumb when a metronome with a frequency of 2 Hz clicked.
(c) Bimanual index-thumb tapping in-phase: Subjects execute the bimanual finger-to-thumb tapping task with the same timing as rapidly as possible.
(d) Bimanual index-thumb tapping anti-phase: Subjects execute the bimanual finger-to-thumb tapping task by touching the index finger to the thumb, alternating between the two hands, as rapidly as possible.
The above tasks (a) to (d) were performed keeping the distance between the two finger tips at 3–4 cm, giving 15 seconds for each bout.

Table 1. Measurement parameters of finger-to-thumb tapping.

1	Max of distance amplitude	23	Max of acceleration amplitude
2	Total traveling distance	24	Avg. of local max. acceleration in extending movement
3	Avg. of local max. distance	25	Avg. of local min. acceleration in extending movement
4	SD of local max. distance	26	Avg. of local max. acceleration in flexing movement
5	Slope of approximate line of local max. points	27	Avg. of local min. acceleration in flexing movement
6	CV of local max. distance	28	Avg. of contact duration
7	SD of local max. distance in three adjacent taps	29	SD of contact duration
8	Max. of velocity amplitude	30	CV of contact duration
9	Avg. of local max. velocity	31	Number of zero crossover points of acceleration
10	Avg. of local min. velocity	32	Number of freezing calculated from acceleration
11	SD of local max. velocity	33	Number of taps
12	SD of local min. velocity	34	Avg. of intervals
13	Energy balance	35	Frequency of taps
14	Total energy	36	SD of inter-tapping interval
15	CV of local max. velocity	37	CV of inter-tapping interval
16	CV of local min. velocity	38	Inter-tapping interval variability
17	Number of freezing calculated from velocity	39	Skewness of inter-tapping interval distribution
18	Avg. of distance rate of velocity peak in extending movement	40	SD of inter-tapping interval in three adjacent taps
19	Avg. of distance rate of velocity peak in flexing movement	41	Avg. of phase difference between the left hand and right hand tapping
20	Ratio of distance rates of velocity peak in extending and flexing movements	42	Standard deviation of phase difference between the left hand and right hand tapping
21	SD of distance rate of velocity peak in extending movement	43	Similarity of hands
22	SD of distance rate of velocity peak in flexing movement	43	Time lag of similarity of hands

Max, Maximum; Min, Minimum; Ave, Average; SD, Standard deviation; CV, Coefficient of variation.
*Avg. of local max. distance (No. 3): Mean of amplitude (local maximum of the distance of each tapping movement) of the waveform of distance.
*Slope of approximate line of local max. points (No. 5): Slope of the linear regression relationship between the local maximum point of distance for each tapping movement and time.
*Number of freezing calculated from velocity (No. 17): Number of times that slight flexing/extending movement other than finger-to-thumb tapping occurred; calculated from velocity.
*Number of zero crossover points of acceleration (No. 31): Number of times that the waveform of acceleration crossed the zero line.
*Skewness of tapping interval distribution (No. 39): Degree of asymmetry of the frequency distribution of tapping interval as compared to the normal distribution.
*Similarity of hands (No. 43): Maximum cross-correlation function between the waveform of distance for the left hand and the waveform of distance for the right hand.

Table 2. Description of measurement parameters.

Parameter No.	Parameter	Description
2	Total traveling distance	Sum of the distance traveled in the flexing and extending movements during a bout. The higher the value of this feature is, the greater the amount of exercise is.
13	Energy balance	Ratio of the sum of squares of velocity in the extending movement to that in the flexing movement. The further this value is away from 1, the more disrupted the balance between the extending and flexing movements is.
29	Standard deviation of contact duration	Variation of the duration that the thumb and the index finger are in contact in one tap. The higher this value is, the more unstable the contact duration is.
36	Standard deviation of inter-tapping interval	Variation of the inter-tapping interval between one tap and the subsequent tap. The higher this value is, the more unstable the tapping interval is.
42	Standard deviation of phase difference between the left hand and right hand tapping	Variation of phase difference between the left hand and right hand tapping. One inter-tapping interval in the right hand is regarded as 360 degrees. The phase difference indicates the gap of the movement of the left hand with reference to the right hand in degrees. The higher value this feature is, the more unstable the gap between the left hand and right hand tapping is.

ered as statistically significant if $p<0.05$. In the present study, five parameters that exhibited a significance level of $p < 0.05$ or a correlation coefficient of $r = 0.6$ or over were extracted (Table 2).

Results

Examples of measured waveforms are shown in Figure 3, in which (A) is the results measured in a healthy female subject in her 70s, whereas (B) is the results obtained from a female patient with AD in her 60s. (A) shows a high number of tapping as well as almost constant traveling distance and velocity. In (B), the traveling distance and velocity are irregular and dispersion is observed in the inter-tapping interval.

1. Comparison between healthy control group and AD/MCI group

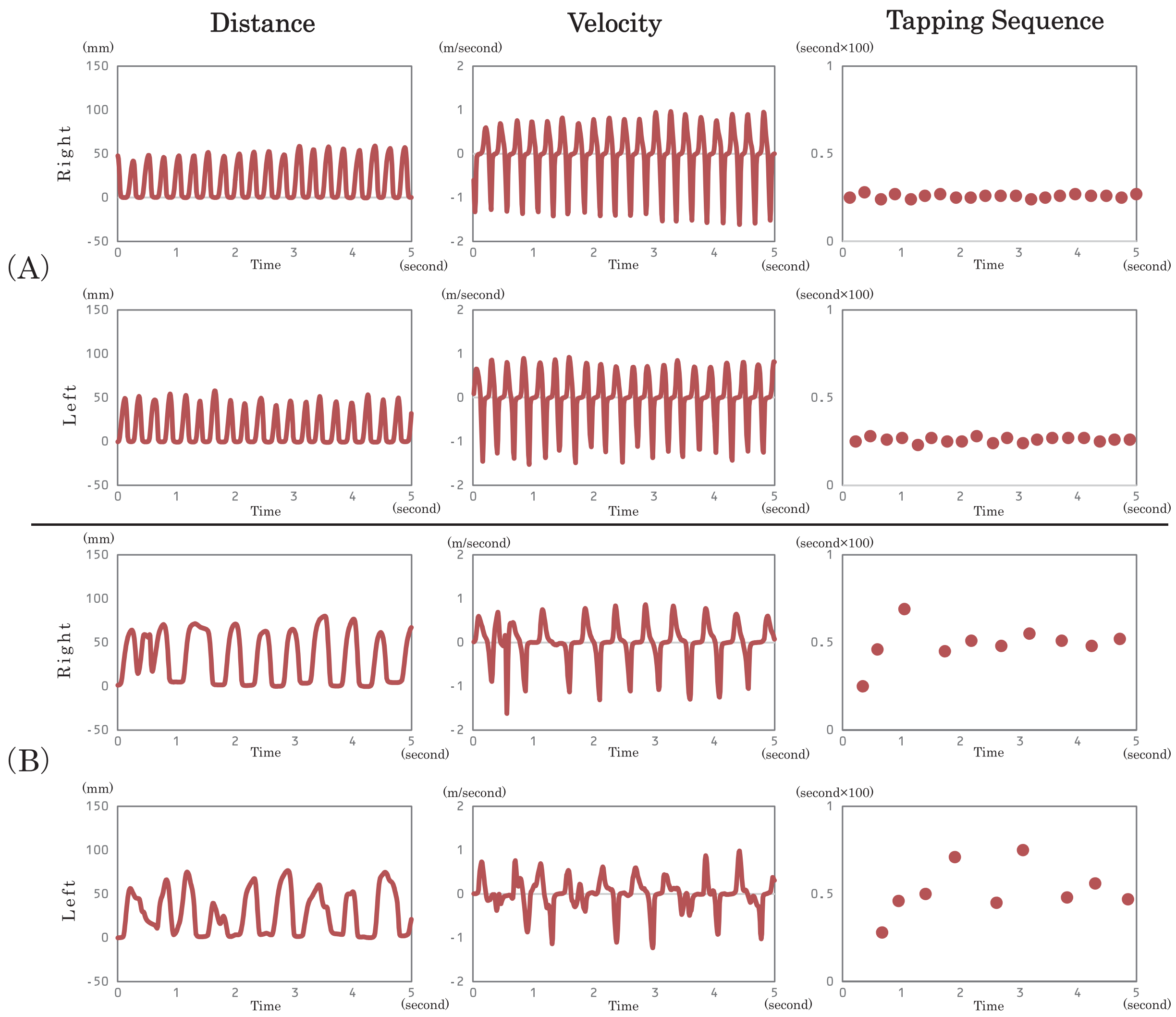
In regard to the movements of the left hand in the anti-phase bimanual task, the AD/MCI group showed smaller total traveling distance (No. 2, $p = 0.03$) and dispersion in movement, i.e. rhythm perturbation (No. 36, $p = 0.03$), compared with the healthy control group. Additionally, in the performance of the left hand in the in-phase and anti-phase bimanual tasks, the duration the two fingers were in contact exhibited a significant difference (No. 29, $p = 0.02$) between the two groups. On the other hand, no significant difference was found in the balance between flexing movement and extending movement (No. 13), or in the dispersion of inter-hand gaps (No. 42) in all tasks (Table 3).

2. Association between finger-to-thumb tapping task and MMSE

Negative correlations with MMSE were observed in the dispersion of the contact durations (No. 29; $r = -0.71$, $p < 0.0001$) and rhythm perturbation (No. 36; $r = -0.64$, $p < 0.001$) in the left hand in the anti-phase bimanual task, as well as in the balance between flexing movement and extending movement with the left hand in the in-phase bimanual task (No. 13; $r = -0.62$, $p < 0.002$) and the dispersion of inter-hand gaps in the in-phase bimanual task (No. 42; $r = -0.78$, $p < 0.0001$). Additionally, a positive correlation with MMSE was found in the total traveling distance of the left hand in the anti-phase bimanual task (No. 2; $r = 0.45$, $p < 0.032$) (Figure 4).

3. Characteristics of the measurement parameters that showed statistical significance

The five measurement parameters referred to above were all finger-to-thumb tapping tasks that used both hands (in-phase bimanual/anti-phase bimanual tasks). Additionally, while one of them was a parameter for both hands, the other four were ones for the left hand, i.e. the non-dominant hand (Table 4). No significant difference or correlation was observed in the finger-to-thumb tapping tasks using the dominant hand (the



(A) Healthy female in her 70s (B) Female AD patient in her 60s

Figure 3. Examples of waveforms exhibited by a healthy subject and a patient with AD.
Distance, waveform of distance; Velocity, waveform of velocity; Tapping sequence, cycle of finger-to-thumb tapping movements.

discrete run with the dominant hand and the finger-to-thumb tapping to a metronome with the dominant hand).

Discussion

Many studies of finger dexterity have documented that dexterity declines with aging [8–12]. Ott et al. [3] reported a decrease in velocity of finger tapping with the right index finger in the AD group compared with the healthy control group in the same age bracket. With respect to the severity of AD, they also found that reduced dexterity [13, 14] and decreased movement velocity [15] occurred in the dominant hand as the disease progressed. Although the results of the present study are in line with their finding that reduced dexterity occurs as AD progresses, the symptom was observed more frequently not in the dominant hand but in the non-dominant hand in our study. The cause of the reduced dexterity in the non-dominant hand may be that the dominant hand is used so frequently in daily life that the daily activities themselves work as training, thereby inhibiting the effect of decline in cognitive function. On the other hand, it is conceivable that the decline in cognitive function manifested more markedly in the non-dominant hand because it is used less often in daily activities compared to the dominant hand.

As factors other than these that affect fine motor skill in older adults, age-related muscular weakness [16] and a potential complication of extrapyramidal disorder [5] have been pointed out.

Previously, no studies have reported analyses of inter-hand finger coordination and rhythm. Coordination and adjustment/stabilization of rhythm are associated primarily with basal ganglia [17]. In addition, corpus

Table 3. Comparison between healthy control group and AD/MCI group.

Task	Hand	Parameter				
		Total traveling distance	Energy balance	Standard deviation of contact duration	Standard deviation of inter-tapping interval	Standard deviation of phase difference between the left hand and right hand tapping
Dominant hand task	Right	6.6 ± 2.6 6.95 ± 2.6 0.75	0.76 ± 0.16 0.8 ± 0.1 0.43	0.03 ± 0.02 0.28 ± 0.01 0.1	0.03 ± 0.02 0.28 ± 0.01 0.3	
Metronome of 2 Hz with dominant hand task	Right	3.3 ± 2 3.3 ± 1.1 0.96	0.42 ± 0.02 0.4 ± 0.11 0.91	0.06 ± 0.02 0.04 ± 0.01 0.06	0.06 ± 0.08 0.02 ± 0.01 0.16	
In-phase task	Left	4.8 ± 1.6 6.3 ± 1.7 0.07	0.82 ± 0.26 0.83 ± 0.14 0.9	0.04 ± 0.02 0.02 ± 0.01 0.02**	0.04 ± 0.03 0.03 ± 0.01 0.2	
	Right	5.1 ± 1.6 6.3 ± 1.7 0.07	0.72 ± 0.17 0.79 ± 0.11 0.17	0.04 ± 0.03 0.02 ± 0.01 0.12	0.03 ± 0.02 0.02 ± 0.01 0.2	
	Left and right					145 ± 49 133 ± 36 0.2
Anti-phase task	Left	3.6 ± 1.2 4.7 ± 1.7 0.03**	0.61 ± 0.16 0.62 ± 0.11 0.95	0.1 ± 0.06 0.05 ± 0.06 0.02**	0.13 ± 0.07 0.07 ± 0.05 0.03**	
	Right	4.4 ± 1.6 5.1 ± 1.6 0.27	0.55 ± 0.19 0.55 ± 0.11 0.94	0.07 ± 0.05 0.05 ± 0.03 0.18	0.11 ± 0.11 0.07 ± 0.05 0.35	
	Left and right					70 ± 60 59 ± 41 0.62

The upper row denotes mean ± SD for the AD/MCI group, the middle row denotes mean±SD for the healthy control group, and the lower row shows the *p*-value.
$p < 0.05$**

callosum function is required for the smooth transfer of information between the right and left brain hemispheres [18]. It has been found that patients with AD suffer atrophy of basal ganglia in addition to atrophy of the temporal lobe/cortex [19]. Furthermore, atrophy and slight transformation in the corpus callosum have also been reported as changes occurring in the early stage of AD [20, 21].

In the present study, differences in finger dexterity between the healthy control group and AD/MCI group were found particularly in the bimanual tasks, which are difficult and require inter-hand coordination to produce rhythm. Especially, since the anti-phase bimanual task is most difficult requiring the subjects to move both hands independently, significant differences were observed in more parameters in the anti-phase bimanual task compared with the in-phase bimanual task. This suggests that the presence of disorder in the basal ganglia or corpus callosum resulted in decreased coordination of finger movements and disturbance in such movements as the anti-phase bimanual task, which requires inter-hand coordination and rhythm. A possible explanation for the lack of difference in finger dexterity in the finger opposition task with the dominant hand only could be that the task was too easy compared with the one using both hands.

In the present study, we compared the finger function and examined the association between severity of dementia and finger function in the healthy control group and AD/MCI group using a magnet sensing finger tapping device. The results showed significant differences between the healthy control

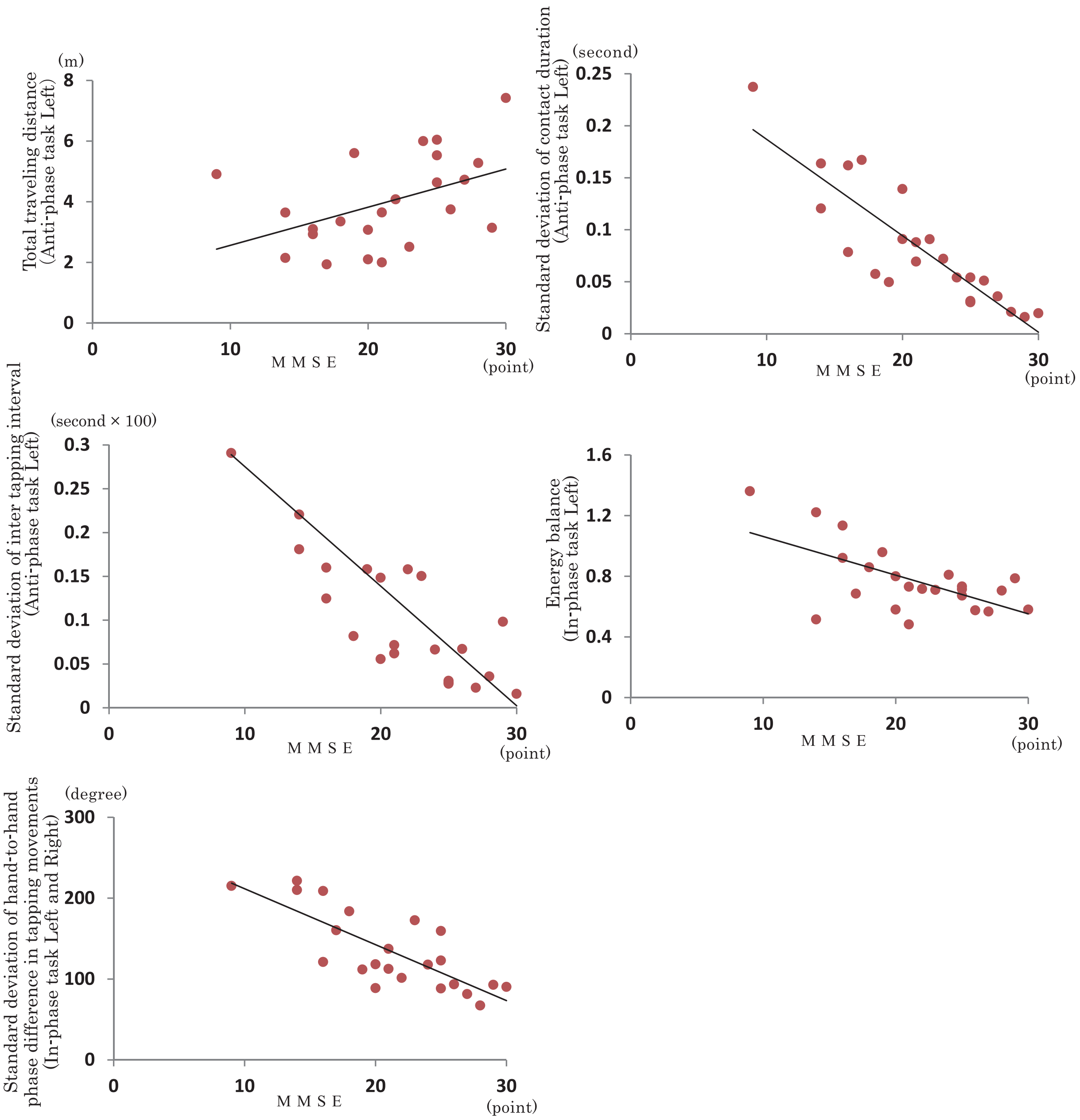


Figure 4. Association between finger function and MMSE.
A scatter chart showing scores of MMSE along the *x*-axis and the values calculated from the finger-to-thumb tapping task for each measurement parameter along the *y*-axis.

group and AD/MCI group in: 1) values of total traveling distance, 2) dispersion of the duration the two fingers were in contact, and 3) rhythm perturbation, indicating decreased ability to perform finger opposition movements in the AD/MCI group compared with the healthy control group. With respect to the comparison with MMSE, significant correlations were found in: 4) balance between flexing movement and extending movement and 5) dispersion of inter-hand gaps, as well as in 1) to 3) stated above. All of these differences were observed in bimanual finger-to-thumb tapping tasks.

Hence, these findings imply that the bimanual finger-to-thumb tapping task—which is difficult to perform—using these parameters may be able to detect individuals at risk for AD and MCI in the older adult population, and that these parameters may be able to be used as an indicator for assessing the progression of AD.

The present study is subject to some limitations. First, the sample sizes of the AD/MCI group and the healthy control group were close to the minimum size required to evaluate statistical significance. Additionally, the method used to compare the healthy control group and AD/MCI group, i.e. matching by age, was not perfect to ensure randomness. Secondly, we did not

Table 4. Summary of the measurement of 5 parameters.

Parameter No.	Parameter	Task	Hand	Result of *t*-test between healthy control group and AD/MCI group	Correlation coefficient with MMSE
2	Total traveling distance	Anti-phase task	Left	$p = 0.03$	$r = 0.45$ ($p < 0.032$)
13	Energy balance	In-phase task	Left	$p = 0.9$	$r = -0.62$ ($p < 0.002$)
29	Standard deviation of contact duration	Anti-phase task	Left	$p = 0.02$	$r = -0.71$ ($p < 0.0001$)
29	Standard deviation of contact duration	In-phase task	Left	$p = 0.02$	$r = -0.44$ ($p < 0.071$)
36	Standard deviation of inter-tapping interval	Anti-phase task	Left	$p = 0.03$	$r = -0.64$ ($p < 0.001$)
42	Standard deviation of phase difference between the left hand and right hand tapping	In-phase task	Left and right	$p = 0.2$	$r = -0.78$ ($p < 0.0001$)

perform assessment specifically of the MCI group, and so a comparison between the MCI group and healthy control group was not carried out in the study. Thirdly, although muscle strength is a factor affecting dexterity, the present study did not measure grip strength or pinch strength. Therefore, taking these factors into account, the evaluation of the results of the present study is inevitably limited. We intend to carry out a more verifiable study including a larger number of subjects and an appropriate control group by recruiting healthy seniors in the community. In future studies, we also plan to measure grasping strength/muscle strength to evaluate the influence of these factors.

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