Reliability of Finger Tapping Test Used in Diagnosis of Movement Disorders

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***Abstract*—We tested the repeatability of a finger tapping device with magnetic sensors to determine its reliability. This device, which was developed to assist in the diagnosis of movement disorders such as Parkinson's disease (PD) and strokes, was used to measure the distance between the thumb and index fingers during finger tapping movements (repeatedly opening and closing the gap between the thumb and forefinger). We evaluated three types of repeatability based on the interclass correlation coefficient (ICC) and analysis of variance (ANOVA), i.e., repeatability when movements were measured at different times, that when movements were measured with different devices, and that when movements were measured by different measurers. We analyzed these three types for three finger tapping tasks on both hands for 21 characteristics calculated from finger tapping waveforms. As a result, repeatability when using different devices was high regardless of the task or which hand was used. Repeatability when movements were measured at different times and when different measurers were used was high in some tasks, but not all. One of the finger tapping tasks (finger tapping movement with the largest amplitude and highest velocity), which is used in a conventional method of diagnosing PD (UPDRS), did not have sufficient repeatability, while the other tasks exhibited high repeatability. These results clearly demonstrate that this device is extremely reliable.**

I. Introduction

The number of patients with movement disorders has recently increased along with the arrival of the aging society. Movement disorders include those induced by Parkinson's disease, cerebral strokes, and chronic rheumatism. The origin of movement disorders ranges from central and peripheral nerves to muscles and joints.

Movement disorders are generally diagnosed by doctors observing the motion of patients in visual and physical examinations. For example, Parkinson's disease is evaluated with the Unified Parkinson's Disease Rating Scale (UPDRS), which is used to score motion in a patient's hands and legs and quantify the degree of motor deterioration. However, this method cannot easily be used to detect slight variations in symptoms. In addition, it also cannot eliminate individual differences between measurers even if they are well-trained doctors.

Therefore, we developed a finger tapping device with magnetic sensors (Fig. 1(a)) to quantify the severity of movement disorders. This device can be used to measure the distance between the thumb and index finger during finger tapping movements [1]. Finger tapping movements involve repeatedly opening and closing the gap between the thumb and index finger, as can be seen from the photographs in Fig. 1(b). This has been adopted as it is a motion that can be used to efficiently quantify the severity of movement disorders with UPDRS.

The measurer places a magnetic generating coil onto the subject's thumb and a detecting coil onto his/her index finger to use this device. The magnetic field generated from the first coil is detected by the second coil. As the strength of the magnetic field varies according to the positional relation between the thumb and forefinger, the distance between them can be calculated from the output of the detecting coil [1]. This method can easily be applied to patients during clinical practice because the device is very compact and extremely accurate.

This device can measure the waveform of the distance between the thumb and forefinger. Various characteristics such as the average amplitude and number of taps are calculated from this waveform. We tried to use these characteristics to distinguish PD patients from normal control (NC) subjects,

(a) (b)

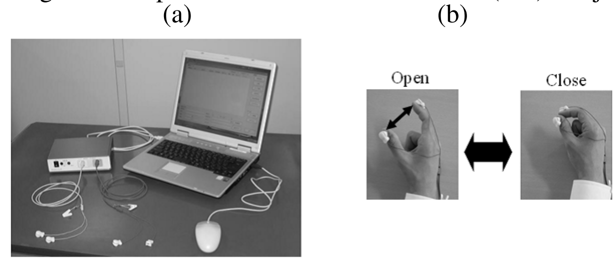

Fig. 1. Finger tapping device with magnetic sensors
(a) Overall view (b) Finger tapping movement

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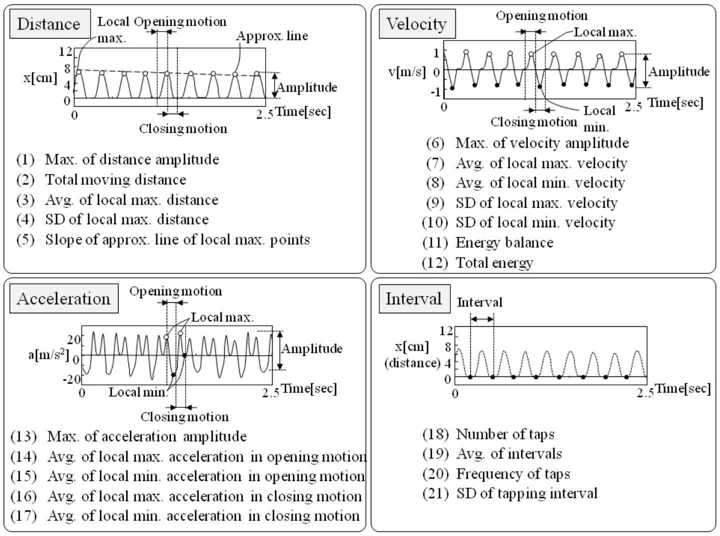

Fig. 2. Definition of characteristics of finger tapping movements

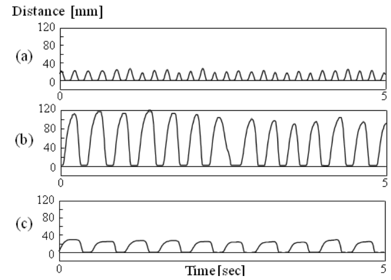

Fig. 3. Distance waveform for finger tapping movements. (a) Task 1 (amplitude of 3-4 cm, tap thumb and forefinger as quickly as possible). (b) Task 2 (digits spread out as much as possible and moving as quickly as possible). (c) Task 3 (amplitude of 3-4 cm at metronome beat of 2 Hz).

and evaluate the efficacy of drugs given to PD patients [2], [3]. However, diagnosis could not be analyzed accurately because these studies did not have a sufficiently large database. To solve this problem, it was necessary for several measurers to assist in building a large database with several devices.

However, the repeatability of finger tapping data becomes a serious problem when different measurers evaluate finger tapping movements with different devices at different times. Finger tapping data are repeatable if the characteristics calculated from these data are invariable even if they are measured by different measurers with different devices at different times.

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Consequently, the purpose of this study was to evaluate three kinds of repeatabilities: ①repeatability when measuring movements at different times, ②repeatability when measuring movements with different devices and ③repeatability when movements were measured by different measurers. In addition, we assessed whether a finger tapping task was highly repeatable by evaluating these three repeatabilities in several tasks.

II. Method

A. Method of measurement

1) Measurement target: This section explains the two groups of normal control (NC) subjects we used to estimate repeatability. Measurement target A was a group for estimating ①repeatability when movements were measured at different times, and measurement target B was a group for estimating ②repeatability when movements were measured with different devices and ③was repeatability when movements were measuring by different measurers. Measurement target A was comprised of 22 healthy male students (age: 20s) from Hiroshima University. Measurement target B was comprised of 368 healthy males and females (ages: 40s-70s) from the same university. We excluded nine people who were ambidextrous from Measurement target B so that we only evaluated repeatability with 359 people. The measurements from A and B were permitted by the Ethical Review Board of Hiroshima University.

2) Condition for measurements: Measurement subject A was measured for eight days. All subjects were randomized to five different days out of eight. Each subject was measured once each day using the finger tapping device with its magnetic sensors manufactured by Hitachi Computer Peripherals Co., Ltd.（Fig. 1(a), prototype）.

Measurement subject B was randomized to five devices and five measurers. The measurers were four males and one female aged from 23 to 27. The devices were five finger tapping devices with the same magnetic sensors.

3) Measurement task: We measured three kinds of finger tapping tasks summarized below for each hand for measurement subjects A and B. These tasks were measured with the subjects' eyes closed for 15 sec.

- Task 1: Amplitude of 3-4 cm with subject opening and closing the gap between their thumb and index finger as quickly as possible
- Task 2: With subject's thumb and index finger spread out as much possible and him/her opening and closing the gap between them as quickly as possible
- Task 3: Amplitude of 3-4 cm and at frequency of 2 Hz

In task 1, a subject executed finger tapping movements as quickly as possible, keeping the maximum distance in each finger tapping cycle at 3-4 cm. In task 2, a subject executed finger tapping movements as quickly as possible, increasing the distance between thumb and forefinger as much as possible. In task 3, a subject carried out finger tapping movements to the beat of a metronome at 2 Hz, keeping the maximum distance in each finger tapping cycle at 3-4 cm. Typical waveforms for the three tasks are in Fig. 3.

Task 2 has been adopted in the finger tapping test by UPDRS, and is an efficient movement that enables accurate diagnosis. However, the same task has been thought to be influenced by the measurer's instructions and demonstration and the subject's interpretation of these. Therefore, we propose

TABLE I

RESULTS FROM EVALUATING THREE KINDS OF REPEATABILITIES

	Characteristics	①Time						②Device						③Measurer					
		Non-dominant			Dominant			Non-dominant			Dominant			Non-dominant			Dominant		
		Task1	Task2	Task3	Task1	Task2	Task3	Task1	Task2	Task3	Task1	Task2	Task3	Task1	Task2	Task3	Task1	Task2	Task3
(1)	Max. of distance amplitude	○	○	○	○	○	○	○	○	○	○	○	○	○*	×*	○	○	×*	○
(2)	Total moving distance	○	○	○	○	○	○	○	○	○*	○	○	○*	○	○	○	○	○	○
(3)	Avg. of local max. distance	○	○	○	○	○	○	○	○	○*	○	○	○	○	×	○	○	○	○
(4)	SD of local max. distance	○	○	×	○	○	×	○	○	○	○	×	○	○*	×*	○	○	×*	○
(5)	Slope of approx. line of local max. points	×	×	×	×	×	×	○	○	○*	×	○*	○	○	○*	○	○	○	○
(6)	Max. of velocity amplitude	○	○	○	○	×	○	○	○	○	○	○	○	×*	×*	○	○	×*	○
(7)	Avg. of local max. velocity	○	○	○	○	○	○	○	○	○	○	○	○	○	×	○	×	×	○
(8)	Avg. of local min. velocity	○	○	○	○	○	○	○	○	○	○	○	○	○	×	○	○	○	○
(9)	SD of local max. velocity	○	○	○	○	○	○	○	○	○*	○	○	○*	○*	×*	○	○	×*	○
(10)	SD of local min. velocity	○	×	×	○	○	×	○*	○	○	○	○	○	○*	×*	○	○	×*	○
(11)	Energy balance	○	○	×	○	○	×	○	○	○	○	○	○	○	○	×*	○*	○	○
(12)	Total energy	○	○	○	○	○	○	○	○	○*	○	○	○	○	×	○	○	○	○
(13)	Max. of acceleration amplitude	×	○	×	×	×	×	○	○*	○	○	○*	○	○*	×*	○	○	×*	○
(14)	Avg. of local max. acceleration in opening motion	○	○	○	○	○	○	○	○	○	○	○	○	○	×	○	○	×	○
(15)	Avg. of local min. acceleration in opening motion	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
(16)	Avg. of local max. acceleration in closing motion	○	○	○	○	○	○	○	○	○	○	○	○	○	×	○	○	○	○
(17)	Avg. of local min. acceleration in closing motion	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
(18)	Number of taps	○	○	×	○	○	×	○	○	○	○	○	○	○	○	○	○	○	×
(19)	Avg. of intervals	○	○	×	○	○	×	○	○	○	○	○	○*	○	○	○	○*	○*	○
(20)	Frequency of taps	○	○	×	○	○	×	○	○	○	○	○	○*	○	○	○	○	○	○
(21)	SD of tapping interval	×	○	×	○	×	×	○	○	○*	○	○*	○	○	○	○	○	○	○

tasks 1 and 3, which involve the fixed amplitude and rhythm of task 2.

B. Method of analysis

1) Characteristics extraction of finger tapping movements: We evaluated the repeatabilities of 21 characteristics from finger tapping waveforms in this study as described in Fig. 2. These characteristics were calculated from distance, velocity, and acceleration waveforms. The latter two waveforms were obtained by differentiating the distance waveform.

2) Method of estimating repeatability: To estimate ①repeatability when movements were measured at different times, we checked if characteristics in five measurements varied applying the interclass correlation coefficient (ICC) to measurement subject A. We regarded an ICC of 0.5 to be highly repeatable. We applied the test to 21 characteristics of both hands in three tasks.

Then, to evaluate ②repeatability when measuring movements with different devices and ③repeatability when movements were measured by different measurers, we applied analysis of variance (ANOVA) to measurement subject B. ANOVA is a statistical method that is used to check the variance in averages of several groups. We regarded a significance probability for ANOVA $\geq$ 5% in this study to be highly repeatable. Before applying ANOVA, we verified Levine's test for equality of variance. We applied such a test to the 21 characteristics of both hands in three tasks.

III. RESULTS

The results obtained from evaluating repeatability are summarized in Table I. The open circles "○" mean characteristics are highly repeatable, and the crosses "×" means they are not highly repeatable. High repeatability means an ICC $\geq$ 0.5 or a significance probability for ANOVA $\geq$ 5%. The asterisks "*" mean high equality of variance obtained with Levine's test (significance probability $\geq$ 5%).

Fig. 4 gives results that sum up those in Table I with respect to three factors (measurement times, devices, and measurers). Focusing on ①repeatability when movements were measured at different times, the repeatability of task 3 is inferior to that of tasks 1 and 2. Focusing on ②repeatability when movements were measured with different devices, the repeatabilities of all tasks is quite high. However, ③repeatability when movements were measured with different measurers for task 2 is rather low.

Taking note of Fig. 4 with respect to tasks, task 1 has the highest repeatability for all three factors (measurement times, devices, and measurers). Task 3 has the second highest repeatability and task 2 has the lowest.

In addition, characteristics which exibit high repeatability in all 18 tests are (2) Total moving distance, (15) Avg. of local min. acc. in opening motion and (17) Avg. of local min. acc. in closing motion (each characteristic is described in Fig. 2).

IV. DISCUSSION

A. Repeatability of factors (measurement times, devices, and measurers)

Table I and Fig. 4 indicate that ①repeatability when measuring movements at different times is high for many characteristics. According to this, no characteristics are influenced when movements are measured at different times.

Table I and Fig. 4 indicate that ②repeatability when movements were measured with different devices is high for almost all characteristics. This means the device is reliable.

However, ③repeatability when movements were measured by different measurers is high for almost all characteristics of tasks 1 and 3, while that of task 2 is not very high for many characteristics. The low repeatability of task 2 may have

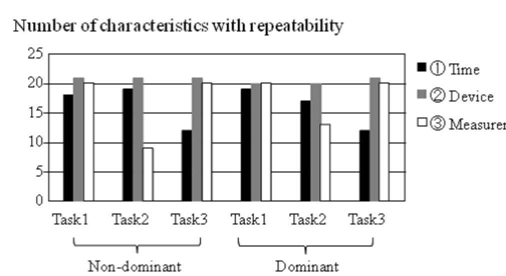

Fig. 4. Number of characteristics with high repeatabilities by factor (measurement times, devices, and measurers) and task

been caused by the different instructions given by the five measurers.

B. Repeatability of tasks

The low repeatability of task 2 described in Fig. 4 was caused by ambiguous instructions such as "spread out your thumb and index finger as much as possible and open and close the distance between them as rapidly as possible", so that subjects could not understand whether amplitude or speed had priority. Therefore, all subjects made their own decisions about which had priority. As a result, repeatability decreased because no clear priority was given to amplitude or speed.

In contrast, because the amplitude of task 1 was limited to 3-4 cm unlike that in task 2, subjects carried out finger tapping movements as quickly as possible in this range. Therefore, as it was unnecessary for participants to make decisions about the priority of amplitude or speed, they only had to move their thumb and forefinger as quickly as possible. Thus, task 1 had the highest repeatability.

We will now discuss why the repeatability of task 3 was lower than that of task 1. As previously mentioned, because task 3 was restricted to both amplitude and speed, it is natural to think subjects did not need to make decisions about these priorities from the viewpoint of limited movements. Repeatability is high according to this idea. However, the repeatability of task 3 was lower than that of task 1. The reason for this is that as the rhythm of task 3 was slow (2 Hz), subjects had to decide how to allocate 0.5 sec to each motion in a finger tapping cycle (opening the gap between their thumb and index finger, keeping it open, closing it and keeping it closed). Compared to this, as subjects in task 1 moved the fastest, it was unnecessary for them to determine such time allocations.

According to this discussion, tasks with high repeatability are those that do not require subject decisions such as those in task 1. As such tasks are rarely influenced by subject mental conditions or measurer instructions, repeatability is high.

C. Repeatability of each characteristic

(2) Total moving distance increases both when amplitude becomes larger and when fingers move faster. Therefore, even if some subjects give priority to amplitude and others give priority to velocity, this characteristic does not vary significantly.

As for (15) Avg. of local min. acc. in opening motion and (17) Avg. of local min. acc. in closing motion, they are considered to represent muscular power when two fingers are open. they exibited high repeatabilities because subjects cannot control fingers easily in this finger posture.

From these discussion, characteristics with high repeatabilities are those which are unaffected by subjects' decision easily.

V. Conclusion

We evaluated three kinds of repeatabilities in this research for 21 characteristics calculated from a finger tapping device with magnetic sensors, i.e., ①repeatability when measuring movements at different times, ②repeatability when measuring movements with different devices, and ③repeatability when movements were measured by different measurers. To evaluate these repeatabilities, five measurers with five devices measured the finger tapping movements of 390 normal control subjects, and applied ICC and ANOVA to these data.

As a result, ①repeatability when movements were measured at different times was high for many characteristics and many tasks. As ②repeatability when when movements were measured with different devices was high for all characteristics and all tasks, the device was verified to be reliable. Even though repeatability was high for all characteristics in task 1 (amplitude of 3-4 cm and open and close thumb-finger gap as quickly as possible) and task 3 (thumb and forefinger spread out as far possible and opening and closing gap between them as quickly as possible) that for ③repeatability when movements were measured by different measurers was low in only half the characteristics in task 2 (amplitude of 3-4 cm and at frequency of 2 Hz). This is because it was difficult for measurers to utter standardized instructions and demonstrate the task of spreading the gap between their thumb and forefinger out as far possible and opening and closing it as quickly as possible.

Focusing on the results for all three tasks, repeatability was high in order of tasks 1, 3, and 2. Focusing on the results for each characteristic, characteristics with high repeatability are Total moving distance, Avg. of local min. acc. in opening motion and Avg. of local min. acc. in closing motion.

As previously described, we could identify an appropriate task by evaluating repeatabilities when different measurers were measuring movements at different times with different devices. This suggests that it is necessary to replace task 2, which has been adopted in UPDRS (the traditional criterion for diagnosing Parkinson's disease), with a new task such as task 1, which is unaffected by measurer instructions or subject mental conditions.

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References

[1] A. Kandori, M. Yokoe, S. Sakoda, K. Abe, T. Miyashita, H. Oe, H. Naritomi, K. Ogata, and K. Tsukada: Quantitative magnetic detection of finger movements in patients with Parkinson's disease, Neuroscience Research, **49**-2, 253/260 (2004)

[2] K. Shima, T. Tsuji, E. Kan, A. Kandori, M. Yokoe, and S. Sakoda : Measurement and Evaluation of Finger Tapping Movements Using Magnetic Sensors, 30th Annual International IEEE EMBS Conference, 5628/5631 (2008)

[3] K. Shima, T. Tsuji, A. Kandori, M. Yokoe, and S. Sakoda : Measurement and Evaluation of Finger Tapping Movements Using Log-linearized Gaussian Mixture Networks, Sensors, **9**, 2187/2201 (2009)

[4] A. Kandori, Y. Sano, T. Miyashita, Y. Okada, M. Irokawa, K. Shima, T. Tsuji, M. Yokoe, and S. Sakoda : Estimation method of finger tapping dynamics using simple magnetic detection system, Review of Scientific Instruments, **81**-9, 054303 1/6 (2010)