Aging Measurements with Precise Observations of Synchronization Hands' Movements

Aging effects on motor control function

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Abstract—**In advanced countries, populations are getting older. Cognitive disorders are an important problem in these countries. We need to measure the deterioration of brain functions with the process of aging. For synchronizing with other motion, we need to feel the other motion, to recognize the motion, to memorize the motion, and to generate the synchronizing motion. We need many kinds of brain functions to perform a cooperative movement. The authors proposed the cooperative visual synchronization task, its' measuring method, implementation and experiments to measure and evaluate the performance of motor control functions. The new task and the measuring method enable to measure the precise movements easily and in a short period of time. The proposed method is safe, because there is no need to attach a device to a subject nor to make exaggerated motions. This paper presents a method to evaluate the aging process of motor control functions using the objective measurement of cooperative movement in both hands, its implementation, and experiments.**

Keywords-aging; aging process; motor control function; measurement; evaluation.

I. INTRODUCTION

With aging, our physical function deteriorates, and also our brain functions do. In advanced countries, our populations are getting older. Our physical deteriorations are measured easily. We need to measure the deterioration of brain functions also. There are tests to measure memory functions and congnitive disorders.

A cooperative movement with other movements is more difficult than simple movements. For instance, clapping hands is easy. However, clapping hands synchronizing with other people is difficult. Synchronizing movement is the base of cooperative movement. For synchronizing with another motion, we need to feel the other motion, to recognize the motion, to memorize the motion, and to generate the synchronizing motion. We may estimate the performance of total brain function by observing the process of synchronizing movement.

There are many motor tasks that measure human motor function abilities. They are the Purdue pegboard task, a seal affixation task, a tray carrying task, etc. [1] - [3]. These tasks estimate human motor function abilities based on the results from the tasks. There is no observation on the process of the tasks. There are also some synchronization tasks used to measure the motor function of a human. One example is a synchronization of finger taps with periodically flashing visual stimuli and synchronization with an auditory metronome. In these tasks, the timing between the stimuli and the tapping is measured. There is no observation about the process of the tapping [4] - [10].

Recently, many cheap and easy measurement methods for the movements of a human body have been developed. For instance, some of these sensors include Kinect sensor, and Leap motion sensor [11] [12]. There are many applications that use these sensors to control computers. For example, there are many video games that use these sensors to control avatars in the games [13].

Using the new motion sensor, we can measure the motion of hands easily and precisely. The human hands are the parts of the body that can make the most complex movements. We have proposed a method that measures the precise movements of hands synchronizing the movements of hands on a display. The synchronization needs visual perception of the displayed hands' images and precise control over the arm muscles. The resulting measure is very sensitive. With this measure, we can observe the performance of the motor function precisely [14].

This paper proposes a new estimation method to evaluate the performance of a brain function of an elderly person with the measurement of a motion control function in cooperative synchronizing movements. We believe this method helps to detect the cognition disorder in early stages.

The rest of this paper is organized as follows. Section II discusses the task to synchronize hands' movements with visual presentation. Next, we discuss the experimental setup in Section III, and show our experimental results in Section IV. Finally, we conclude this work in Section V.

II. VISUAL SYNCHRONIZATION TASK

There are many motor tasks that intend to measure the motor function of a human. However, most of these tasks measure the results from the tasks. There are some tasks that measure the synchronization between a finger tap and stimuli. With human observations, it is difficult to measure the process of synchronizing movements. Now, we can use a Kinect sensor and a Leap Motion sensor. These sensors measure the three-dimensional movements of a human body. With these sensors, we can measure the precise movements of a human body.

We can synchronize our movements with each other. For instance, when dancing, dancers can synchronize their movements with each other. A synchronization of movement is more difficult work than a simple imitation of movement. To generate synchronized movements, we need to observe

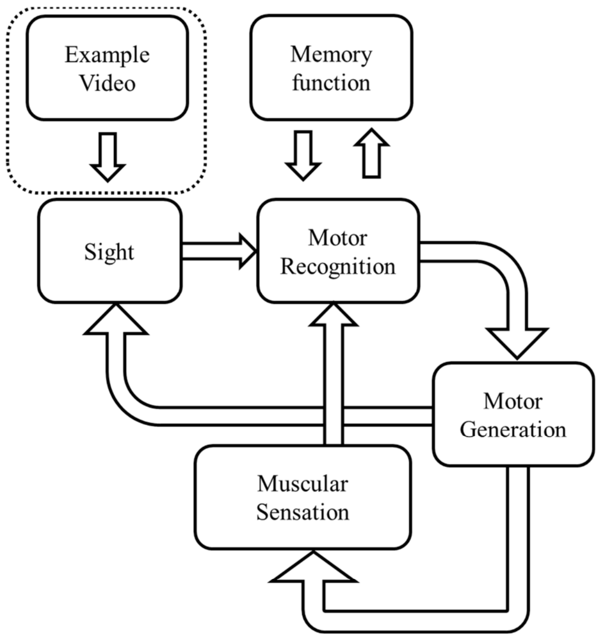

Figure 1. Relations among functions.

the motion to be synchronized. We need to generate the motion to be similar to the motion synchronized. We need to observe the generated motion synchronizing the original motion. We need to estimate the divergence between the original motion synchronized and the motion synchronizing the original motion. We need to control the speed of the motion synchronizing. These functions form a feedback loop. However, there is a delay in our processing. To compensate our brain's processing delay, we need to estimate the delay itself and make proper amount of feedforward.

This processing loop is shown in Fig. 1. For estimating the total brain function, we need to include all the functions of the brain. The visual synchronization task includes vision and motor functions. The vision includes not only the static sight, but also the dynamic sight.

The visual synchronization is more difficult than audio synchronization. So, we observe the wider brain functions with the visual synchronization tasks than the audio synchronization tasks.

Our proposed visual synchronization task is the synchronization between the position of stimuli on a display and the position of the hands. Our synchronization task is not the synchronization between the timing of the stimuli and the timing of action. The measurement of timing is only one scalar value in a cycle of stimuli. In our proposed synchronization task, the measuring result is a sequence of triples of the positions of the stimuli and the ones of subject's hands in a cycle of stimuli. For instance, we have 100 measurements in a cycle of stimuli.

A. Motion synchronization measure

We define the synchronization measure using Fast Fourier Transform (FFT) results of the estimated poses of both hands in each cycle. If a subject makes complete synchronization to the stimuli, the resulting pose of both hands follows a complete sine curve. As a result, at every cycle of the rotation of hands, the result of FFT has a zero value at the second term or higher terms. We define the measure as (1). This measure increases with the distance from ideal sine curve.

$$NSM = \left(\sum_{x=2}^{t/4} m_x \right) \Big/ m_1 \qquad (1)$$

In (1), t is the number of terms. m_x is the absolute value of the x-th term of the result of FFT. m_1 is the power of the lowest frequency. This represents one cycle of a hand's rotation. If the rotation of a hand follows the stimuli images precisely, m_1 carries all powers of the hand's rotation. Other terms carry no power. In that case, the measure in (1) is 0.

m_0 is a value that represents the average of poses. This is not included in (1). As a result, this measure does not depend on the absolute poses of hands.

We call this measure as Non-Smoothness-Measure (NSM). This measure may span from 0 to infinity.

Our proposed system observes two hands. So at every cycle, we have two NSMs.

B. Phase

The NSM is the measure of the difference of a motion based on the displayed motion. However, there is a difference of timing between the displayed motion and a user's motion. The tapping test measures the difference between a stimulus and the response of a user. In the proposed synchronization task, the difference in timing is the difference of phases.

In the result of FFT, there are phases of all frequencies. In our experiments, these are from 0 Hz to 50 Hz. The signal of 1 Hz represents the ideal motion based on the proposed example motion. Therefore, we use the phase of the signal of 1 Hz for evaluating the timing of the motion.

III. EXPERIMENTS AND DISCUSSIONS

A. Experiments Setup

From the pre-experiments, the speed of the hands' rotation is best at one cycle per second. Subjects need about three cycles to synchronize their movements of hands to the proposed motion images and remember the motion. As a result, one trial of an experiment needs at least 11 S. For getting reliable results, we decided that the length of a trial would be 25 cycles of rotations. This means that one trial needs 25 S. Fig. 2 shows the relations among parts, cycles, and sections in a trial. A cycle is one flip of hands. There are two parts. One part is an example displaying part. The other is no-example displaying part. The sections are periods to analyze measured data. The first section shows the status of a subject in the motion example displaying part. The second section does the status just after the disappearance of the motion example. The third section shows the status a few

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seconds after the example motion disappears. Before starting a trial, we instruct subjects to synchronize their hands to the displayed hands' images and continue to move the hands after the example motion disappears.

B. Experiment

1) Young and Healthy People

We obtained 156 valid trials with four healthy, male students, with ages between 23 - 24 years old. At each trial, we have 25 pairs of NSMs and 25 pairs of phases, at most. In many cases, a subject could not move his hands as the displayed hands at the first cycle. The NSM shows the difference of the motion of subject's hands from the proposed example motion. The phase represents the difference of the timing between the proposed example motion and the motion made by a subject.

2) Elderly people

We performed experiments with elderly people, 75 years old in average. They are all healthy for their age. In our observation, one female has difficulty walking. So, we have 14 healthy elderly people, four males and ten females. Each one made two trials, for a total of 28 trials. One trial had a failure in measurement. We obtained 27 valid measurements of the trials.

3) Measure for a trial

In a single cycle, the measured movements of hands may match the proposed example movements accidentally. We estimate the performance of the motion control function with the average motions in three continuous cycles. And, we estimate the performance of a subject in a trial with the best movements in the averages of three continuous cycles.

Equation (2) defines the performance of a hand in a trial.

$$\mathrm{NSMH} = \min_{i=1,8} average(NSM_i, NSM_{i+1}, NSM_{i+2}) \quad (2)$$

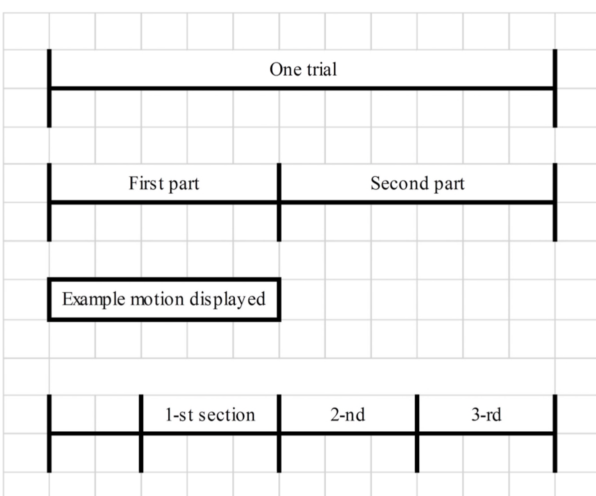

Figure 2. Relations among a session, phases and sections

NSMH is the performance of a hand in a trial. NSM_i is the *NSM* at i-th cycle defined as (1). We have two NSMHs in a trial. They represent the performances of both hands.

We define the performance measure in a trial as (3).

$$\mathrm{NSMT} = \min(NSMH_L, NSMH_R) \quad (3)$$

In (3), NSMT is the performance measure in a trial. $NSMH_L$ is the NSMH of the left hand. $NSMH_R$ is the NSMH of the right hand. This NSMT represents the performance of a subject in a trial.

IV. RESULT AND DISCUSSIONS

A. NSMs

1) Young people

Table I summarizes the NSMs at each cycle in young people. At the first cycle, a subject tries to synchronize his hands' motions with the displayed example motion. The average NSM of the first cycle is larger than other cycles. After three cycles, a subject completes the synchronization of his hands to the displayed motions. The NSMs at cycle 3 to cycle 10 are low. At the start of cycle 11, the example hands image disappears. The NSM at cycle 11 increases a little. The differences among cycles are small. Fig.3 shows the average of NSMs in each cycle.

In our experiments, the memory related to simple motion is good in the first five seconds from the disappearance of the

TABLE I. NSMS.OF YOUNG PEOPLE

Cycle	Example motion	Average	Standard derivation
1	Y	0.390	0.153
2	Y	0.266	0.058
3	Y	0.267	0.060
4	Y	0.253	0.054
5	Y	0.256	0.062
6	Y	0.255	0.061
7	Y	0.257	0.103
8	Y	0.252	0.056
9	Y	0.252	0.062
10	Y	0.248	0.059
11	N	0.265	0.070
12	N	0.261	0.074
13	N	0.265	0.078
14	N	0.267	0.068
15	N	0.269	0.076
16	N	0.270	0.083
17	N	0.290	0.135
18	N	0.306	0.185
19	N	0.299	0.151
20	N	0.284	0.147
21	N	0.351	0.771
22	N	0.316	0.355
23	N	0.378	1.086
24	N	0.405	1.468
25	N	0.315	0.156

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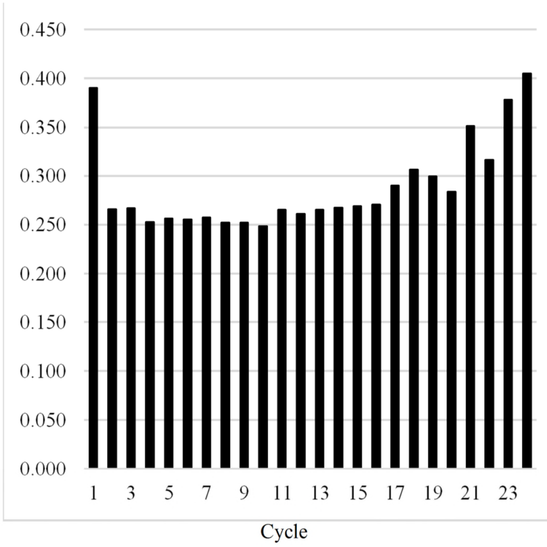

Figure 3. NSMs of each cycle in young people.

proposed example motion shown in Fig. 3. After five seconds, there is a little loss in motion precision.

We computed the difference between the distribution of the NSMs at cycle 10 and the distribution of other cycles after cycle 10.

We confirm that they have the same distributions using t-test. Table II shows the probability of sameness of the distributions from one of the cycle 10. Fig. 4 shows the probabilities. From cycle 13 to cycle 19, the probabilities are decreasing. This shows that the short-term memory of motor function decrease rapidly. After cycle 20, subjects lost the memory about the motion, and their hands' motions became more random.

With NSMTs, we estimate the performance of the younger people in synchronizing their hands' movement to the displayed hands' movement. Fig. 5 shows the distribution of NSMTs of younger subjects. The NSMTs concentrate around 0.2.

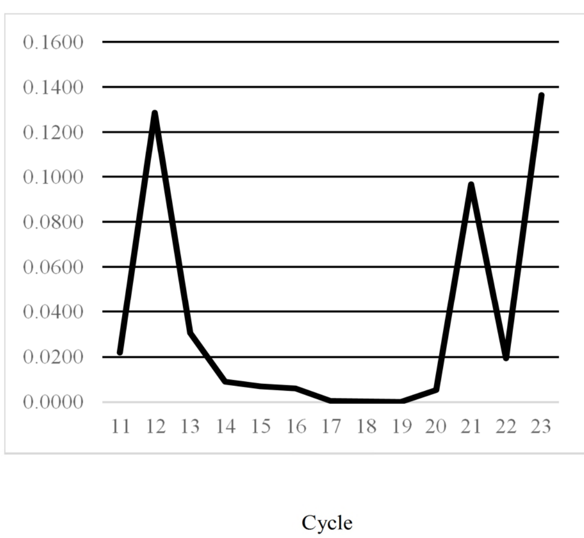

Figure 4. Probabilities of the sameness of the NSMs distributions.

2) Elderly people

Table III summarizes the NSMs at each cycle in elderly people. At the first cycle, an elderly subject synchronizes his hands' motions to the displayed example motion. The average NSM of the first cycle is larger than other cycles. After six cycles, a subject finishes to synchronize his hands to the displayed motions. The NSMs at cycle 4 to cycle 10 are low. At the start of cycle 11, the displayed example hands

TABLE II. PROBABILITIES OF SAMENESS OF NSM TO THE CYCLE 10.

Cycle	Probability of sameness
11	0.0219
12	0.1287
13	0.0305
14	0.0091
15	0.0070
16	0.0060
17	0.0005
18	0.0002
19	0.0001
20	0.0053
21	0.0966
22	0.0194
23	0.1365

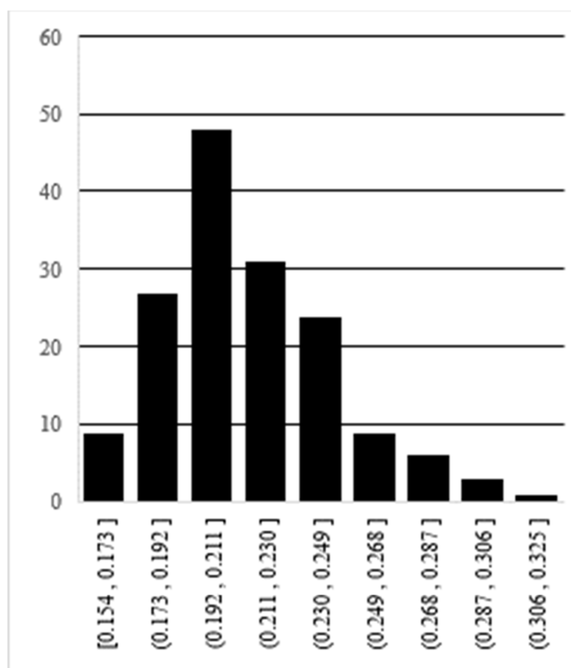

Figure 5. Distribution of NSMTs of young people.

image disappears. The NSM increases from cycle 11 to cycle 14. The differences between cycles are not large. Fig. 6 shows the average of NSMs in each cycle.

3) Comparison between young people and elderly people

We have 158 NSMTs of young people and 27 NSMTs of elderly people. On average, the NSMTs of young people are smaller than the NSMTs of elderly people. However, we need to check the reliability. We perform a t-test with these two groups of NSMTs. Table IV shows the result of the t-test. The probability of being the same is less than 10^{-9}. The deference between young people and elderly people is significant. This implies that NSMT can measure the deterioration as a result of the aging process. There is an apparent difference between NSMs of young people and ones of elderly people, as shown in Fig. 3 and Fig. 6.

TABLE III. NSMS.OF ELDERLY PEOPLE

Cycle	Example motion	Average	Standard derivation
1	Y	1.474	0.953
2	Y	1.057	1.212
3	Y	0.887	1.069
4	Y	0.800	1.044
5	Y	0.645	1.016
6	Y	0.490	0.393
7	Y	0.511	0.376
8	Y	0.575	0.654
9	Y	0.438	0.218
10	Y	0.433	0.221
11	N	0.723	0.637
12	N	0.921	1.263
13	N	0.600	0.580
14	N	0.787	0.997
15	N	0.711	0.667
16	N	0.549	0.471
17	N	0.508	0.396
18	N	0.588	0.500
19	N	0.700	0.567
20	N	0.648	0.551
21	N	0.753	0.703
22	N	0.773	0.737
23	N	0.644	0.509
24	N	0.559	0.512
25	N	0.565	0.125

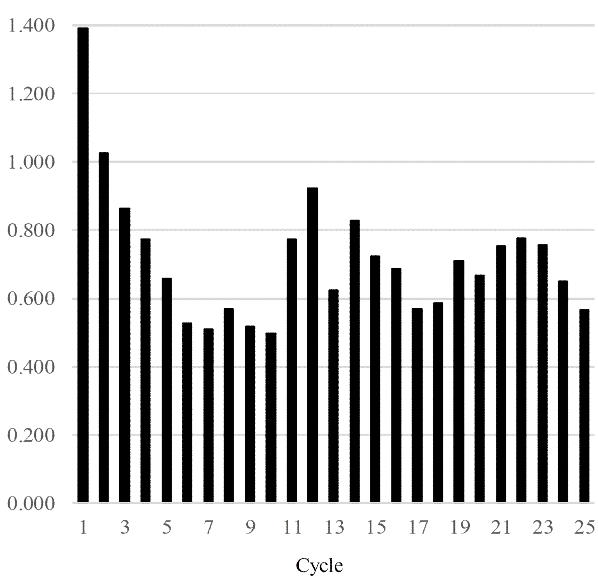

Figure 6. NSMs in each cycle on elderly people.

TABLE IV. T-TEST BETWEEN NSMTS OF YOUNG AND ELDER/

	Elder	Young
Average	0.395186	0.214459
Distribution	0.009645	0.000892
#samples	27	158
Freedom	27	
t	9.487605	
P(T<=t)	2.17E-10	
t	1.703288	
P(T<=t) Both	4.33E-10	
t both	2.051831	

4) Aging in NSMTs

In elderly people, the deterioration of motor control function increases with the aging process. Fig. 7 shows the relation between the age and the NSMT of each elderly person. The correlation coefficient between the age and the NSMT of elderly people is 0.467. There is a linear relation between the age and the NSMT. The linear approximation is (4).

$$\mathrm{NSMT} = 0.0088\mathrm{a} - 0.26 \qquad (4)$$

In (4), NSMT is the performance measure of motor control function. a is the age of a subject. The age ranges between 66 years old and 83 years old.

The average of NSMTs is about 0.2 in young people. If the deterioration of motor control function shows a linear

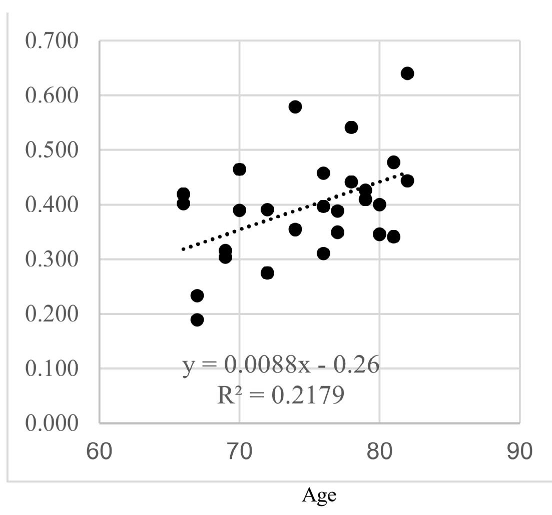

Figure 7. Age-NSMTs relation of elderly people.

relation with the age of a subject from the start of the deterioration, we can estimate the motor control function age with (5) over 53 years old people.

$$\mathrm{NSMA} = 114\mathrm{MSNT} + 29.5 \quad (5)$$

In (5), NSMA is an aging years of motor control function. NSMT is a measured NSM at a trial. This shows the measurement of motor control function can estimate the aging of a brain function of elderly people.

B. Phases

The phase of the measured motion represents the timing of motion. In phases, there is apparent difference between the first period where the example motion is displayed and the second period where the example is not displayed in a trial. In the part from cycle 1 to cycle 10, the phases keep a similar value. From cycle 11, the phases change gradually. This represents the difference between the speed of the example motion and one of the memorized motions. From this phase change, we can measure the difference of timings between the example motion and the memorized motion.

1) Young people

We assume that the phase change in the first part of a trial is smaller than the phase change in the second part of the trial. We divided all cycles into three sections. To confirm this assumption, we calculate the linear approximation of the phases in each section. The first section starts from cycle 4, and ends at cycle10. The second section goes from cycle 11 to cycle 17. The third section goes from cycle 17 to cycle 23, as shown in Fig. 2. In 158 valid trials, there are delays and advances in phases. We evaluate phase change in absolute value.

TABLE V. PHASE CHANGES IN SECTIONS OF YOUNG PEOPLE.

Section	Cycles	Slant of phase change
1	4-10	0.022
2	11-17	0.111
3	17-23	0.113

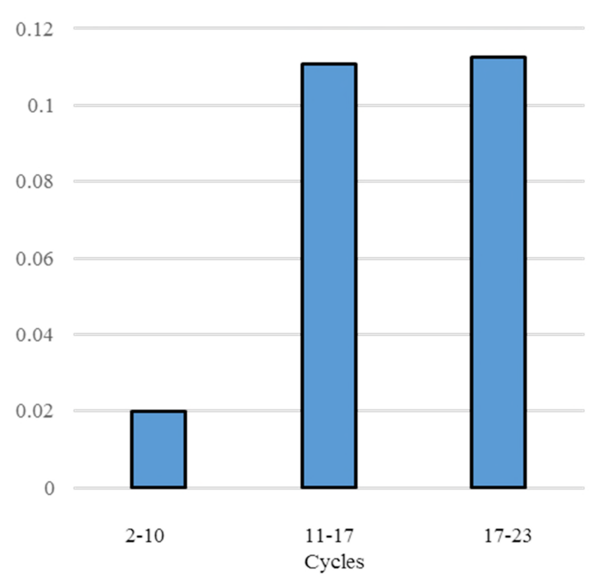

Figure 8. Phase changes in cycles.

Table V shows the averages of the slant of each section. The average absolute slant of phases in the first section is smaller than the one in the second section and the third section. Fig. 8 shows this relation. In Fig. 8, there is an apparent increase of phase changes in 2nd and 3rd sections.

Statistically, the first section and the second section have difference bases. Calculation of the t-test confirms that the difference is significant. The t-measure between these two sections is over 12. The probability is under 10^{-26}. The t-measure between the second section and the third section is 0.18. The probability is over 0.85. This confirms that the second and the third sections have a same base. This result means that the memory about the timing of motion remains for at least 15 seconds.

2) Elderly people

We also calculate the linear approximation of the phases. Table VI shows the average absolute slant of phase's change in each section.

There are apparent differences of the phase changes between young people and elderly people. Elderly people have some difficulties to keep the pace of flipping their hands. In phases, it is difficult to find the proper scale representing an aging process.

C. Discussion

With the NSMs, there is no apparent change between with and without a displayed motion example. Before 15 seconds, there is little decay of the memory of motion. After 16 seconds, Fig. 3 shows a little increase of the NSMs.

With the phases, there is apparent difference between with and without a displayed motion example. The changes of measured phases represent an error in the timing of a measured motion. Some trials show delay, and others show advance. The phase change shows the error about the memory of the timing. The proposed method measures the timing and the process of movements. A classical tapping test measures the timing only. However, in this experiment, the difference of 0.001 radian in phase is the difference of 0.00016 seconds in time. The proposed timing measure about motor function based on the phase of the basic movement is very keen. The classical tapping test can measure the difference of 0.0001 seconds now. However, the mechanical features about a hand and a switch make it difficult to measure the small difference of time.

V. CONCLUSION

This paper proposes the pair of the measurement and evaluation method of motor control function to estimate the deterioration with an aging process. The proposed method is implemented and tested in experiments. The task is easy to perform. For instance, it needs only 25 seconds. The

TABLE VI. PHASE CHANGES IN SECTIONS OF ELDERLY PEOPLE.

Section	Cycles	Slant of phase change
1	4-10	0.146
2	11-17	0.323
3	17-23	0.373

proposed Non-Smoothness Measure has enough power of discrimination of a motor control function. The phase changes also have enough power to measure the very small error in timing remembered.

The experimental results confirm that the proposed method can measure and evaluate the deterioration of a motor control function with an aging process precisely. This paper proposed a method to estimate the age according to the aging process of the motor control function. This age helps to measure the deterioration of the brain function, and it can detect the very first stage of cognitive impairment. We will perform larger scale experiments in the next step.

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