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Development and Aging on Motor Control Function with Precise Observations of Synchronization Hands' Movements

Kyota Aoki and Hisanori Hotta
Graduate school of Engineering, Utsunomiya University, Utsunomiya, Japan
e-mail: kyota@is.utsunomiya-u.ac.jp hisanori6432@yahoo.co.jp

Abstract—**In advanced countries, populations are getting older. Cognitive disorder is a large problem in the countries. To understand the cognitive disorder with aging, we need to have a whole image of the development and the aging of our cognitive functions. We need to measure the performance of brain functions with the process of development and aging. For synchronizing with other motion, we need to feel the other motion, to recognize, to memorize, and to generate the synchronizing motion. We need many kinds of brain functions to make synchronizing movement. The authors proposed the cooperative visual synchronization task, its measuring method, implementation and experiments to measure and evaluate the performance of motor control function. The new task and the measuring method enable to measure the precise movements and evaluate the performance of motor control function easily in a short period. The proposed method is safe, because there is no need to attach the device to a subject nor to make exaggerated motions. This paper presents the results of experiments about primary school pupil, high-school students, young students, manhood people and elderly people. In addition, the authors show the overview of development and aging process of motor control function from objective measurement of cooperative movement in both hands.**

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

I. INTRODUCTION

Our brain function starts its development from the age of infant, keeps its performance in manhood, and deteriorates with aging. There is no overview about our brain performance from infant to elderly people in single measure. IQ test can be applied to wide range of ages. However, the IQ test needs much time. The IQ test is not the same in all range of ages. The IQ test for an infant is not same with the one for a young adult.

With aging, our physical function deteriorates, and also our brain functions [1]. In advanced countries, the populations are getting older. Our physical deteriorations are measured easily. Also, we need to measure the deterioration of brain functions. There are tests to measure the memory functions and the cognition 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, to memorize, and to generate the synchronizing motion. We may estimate the performance of total brain function observing the process of synchronizing movement. Because of it, we need to work many brain functions to complete the synchronizing movement.

Many motor tasks measure the performance of human motor function. They are the Purdue pegboard task, a seal affixation task, a tray-carrying task, etc. [2] - [4]. These tasks estimate the performance of human motor function based on the results from the tasks. There is no observation on the process of completing the tasks. Some synchronization tasks measure 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 [5] - [11].

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 [12] [13]. Many applications use these sensors to control computers. For example, many video games use these sensors to control avatars in the games [14].

Using the new motion sensor, we can measure the motion of hands easily and precisely. The human hands are the parts of a 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 [15].

This paper proposes the overview of development and aging process of our brain with a new estimation method to evaluate the performance of a brain function by the measurement of a motion control function in cooperative synchronizing movements. To draw the outline of the development and the aging process, this paper needs many age groups that spans from infant to elderly people. This paper includes the experiments about primary school pupil, high school students, young, manhood, and elderly people. In this paper, there is no infant and junior high school student. However, this paper can show the outline of development and aging of brain function in a single measure.

The rest of this paper is organized as follows. Section II discusses a task to synchronize hands' movements with visual presentation. Next, we discuss the experimental setup in

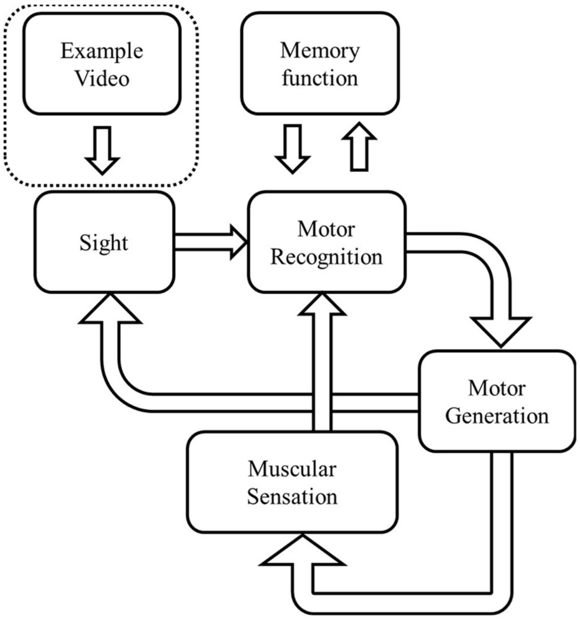

Figure 1. Relations among functions.

Section III, and show our experimental results in Section IV. Finally, we conclude this work in Section V.

II. VISUAL SYNCHRONIZATION TASK

A. Task and Brain Function

Many motor tasks intend to measure the performance of the motor function of a human [2] - [4]. Motor function is not a strength of muscles. The strength of muscles is one measure of our body performance. We may have problems of our muscles in the case that we cannot have a good performance of motor functions. For the people with healthy body, their brain performance decides the performance on motor tasks. Those motor tasks measure the performance of some motions. However, most of these tasks measure the results from the tasks. They do not measure the process of motions directly.

Some tasks measure the synchronization between a finger tap and stimuli [5] - [11]. With human observations, it is difficult to measure the process of synchronizing movements. Classical works measure the timing of pushing a switch. 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 in groups, dancers can synchronize their movements with each other. A synchronization of movement is a more difficult work than a simple imitation of movement. To generate synchronizing movements, we need to observe the motion 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 a proper amount of feedforward. Therefore, our brain functions have a feedback loop and a feedforward loop.

This processing loop is shown in Fig. 1. For estimating the total brain function, we need to include all the functions of the brain. In this paper, we call the task that a subject synchronizes one's movement to the displayed movement, as the visual synchronization task. 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 task is more difficult than audio synchronization. Therefore, 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 pose of stimuli on a display and the pose of the hands. Our synchronization task is not the synchronization between the timing of the stimuli and the timing of the action. The measurement of timing gets only one scalar value in a cycle of stimuli. In our proposed synchronization task, the measuring result is a sequence of the triples of the pose of subject's hands in a duration of stimuli. For instance, we have 100 triples of floating numbers in a second.

B. Stimuli of Visual Synchronization Task

For the motor task, the authors select the rotation of both hands. Rotation is a difficult movement with a hand. For analyzing the synchronization easily, the authors make the stimuli that rotation angles follow a precise sine curve. Fig. 2 shows the example of a pure sine curve. If stimuli form precise sine curves, we easily evaluate the observed motion comparing with the pure sine curve.

Our stimuli are a displayed video of both hands' rotation. Fig. 3 shows some frames of a hands' rotation video for the visual synchronization task. In a real world, it is difficult to control precisely the motion of hands to follow the pure sine curve. If the stimuli images do not follow the pure sine curve,

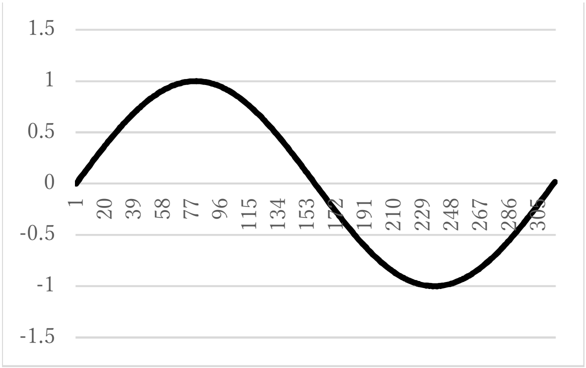

Figure 2. An example of a pure sine curve.

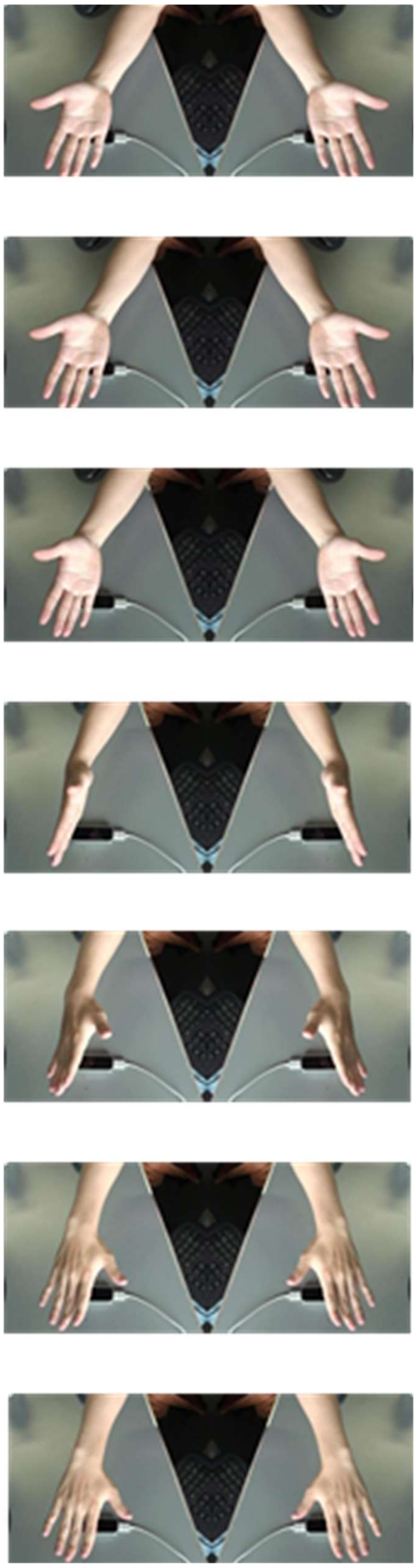

Figure 3. Stimuli Images.

it is also difficult to evaluate the synchronization between the stimuli images and the motions of hands. We can use many measures. For instance, the square error of the poses between stimuli and hands can work as the performance measure of the observed hands' movements. However, the square error changes in the scale of movements of hands. This paper needs the method to measure the performance of the motor control function. The flexibility of our arms must not affect the performance measure. Therefore, square error is not fit for our purpose. Using a pure sine curve as stimuli, we can estimate the performance of our hands' movements with invoking a signal-to-noise ratio based on the communication theory. This proposes a strict base to the proposed measuring method for the performance of the control function.

C. *Implementation*

Fig. 3 shows the sequence of stimuli examples. The total sequence of stimuli includes 67 images. The images are proposed on a display with a constant interval from top to bottom. Then, they are proposed from bottom to top. These two sequences make one cycle of the stimuli of hands' motion. In the stimuli images, the right hand and the left hand are the same pose. The right one is the mirror image of the left one.

The authors propose the stimuli generation method that displays a proper image at the precise timing. The authors recorded the motion of hand's rotation with a camera and the Leap-motion sensor simultaneously using a PC. The records include the precise time stumps. From the recorded images and measured rotation angles, we constructed the sequence of images that rotations follow a pure sine curve.

In displaying images on a display, there is some delay or progress of a timing. Our implementation controls the timing of displaying each frame with selecting the best-fit frame at the timing. As a result, our implementation displays smooth transition between successive frames.

Our implementation has two sub-processes. The one sub-process displays the stimuli images. The other sub-process measures the pose of hands. With this multi-processing, our implementation enables to show the stimuli and to measure the reaction of a subject in the best performance.

In the following experiments, one cycle of hands' rotation is completed in a second. We can rotate our hands 1.5 cycle at a second. However, 1.5 cycle at a second is too fast for many subjects in our previous experiments.

We can rotate our hands much more slowly. However, in slow rotations, we can easily follow the position of displayed hands' image. In the case, we do not synchronize our movements to the displayed hands' movements. We only imitate the poses of the displayed hands. There is no synchronization of movements. Therefore, we cannot use much slower movements.

We measure the pose of hands with the leap-motion sensor [13]. The sensor measures the poses of hands 100 times for a second. As a result, we have two measurements of the poses of hands in each cycle of hands' rotation. The leap-motion sensor measures the three-dimensional pose of a hand. We use only the rotations around forearms.

D. Motion synchronization measure

We define the synchronization measure using Fast Fourier Transform (FFT) results of the measured rotations of poses of both hands in each cycle [16]. If a subject makes complete synchronization to the stimuli, the resulting poses of both hands follow a pure 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 representing the noise-to-signal ratio as (1). This measure increases with increasing the difference from ideal sine curve.

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

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 zero. The result FFT has much higher terms from *t*/4+1 to t. The t/2 or higher terms are mirrored of lower terms. Therefore, we need only treat a *t*/2 or lower terms. Under *t*/2 terms, there are many noises in upper terms. In a normal processing of FFT, we use window function to decrease the noises in observations. However, the authors define the measure at each cycle. Therefore, it is difficult to use window function. Therefore, the authors use only lower half of the all terms. If we can have 100 measurements in a cycle, we use 25 terms. They represent the motion at every 1/50 seconds. This is enough precise for observing our brain control loop.

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.

Some people rotate their hands largely. Others do not. (1) is the ratio between a signal and a noise. Therefore, the scale of rotations does not affect the measure. We call this measure as Non-Smoothness-Measure (NSM). This measure may span from zero to infinity.

Our proposed system observes two hands. Therefore, at every cycle, we have a pair of NSMs.

E. Phase

The NSM is the measure of the difference of a motion from 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. 0-th term carries a constant pose. Therefore, it has not a phase. The first term represents the signal of the stimuli. Therefore, the authors use the phase of the first-term to estimate the phase of the motion of a hand.

In our experiments, these are from 1 Hz to 50 Hz of terms of FFT. 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

1) Precise type

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. For measuring a stable result, we need at least three cycles. As a result, one trial of an experiment needs six cycles at least. However, there may be some error measurements. For stable measurements, we need some redundancy. The authors decide 10 cycles to measure the hands' movements synchronizing the displayed stimuli images. After the stimuli images disappear, the authors want to observe the decay of the motion memory. Therefore, the authors observe the motion of hands in fifteen seconds. There is no ground about the length of observation. However, a subject feels 30 seconds of a trial to be very long. For getting reliable results, we decide that the length of a trial is 25 cycles of rotations. This means that one trial needs 25 S. Fig. 4 shows the relations among parts, cycles, and sections in a trial. A cycle is one flip of hands. There are two parts in a trial. 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 at some 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.

2) Simple type

In a large-scale measurement, the precise type measurements is too long. It needs at least 25 sends to complete. Moreover, there are many error measurements. Because, many subjects cannot keep their hands' movements

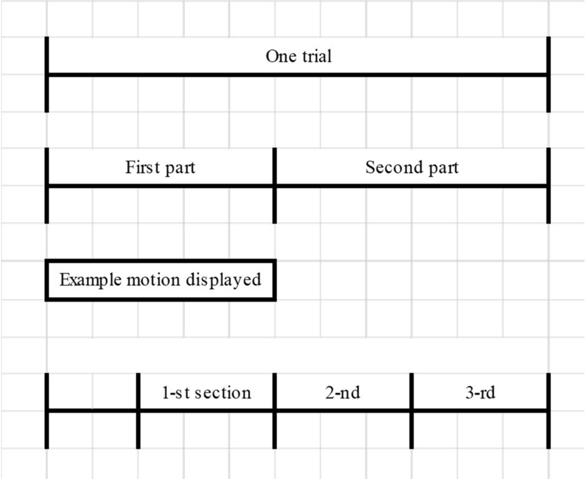

Figure 4. Structure of precise measurement.

after the displayed hands' movements disappear. In a large-scale measurement, the total length of measurements must be long. In a long term, there must be some changes of environment. In the case, the ratio of error measurement increases. However, the authors hope to have a valid trial with some error measurements. Therefore, the authors define the trial that includes only the example displayed part. The authors increase the length of the example displaying part increase to fifteen seconds. This is a simple type trial.

Our simple type of visual synchronization task has no measurements of poses of hands without displayed hands' movements. To measure enough valid data, the length of measurement is 15 cycles of hands' rotations. A trial needs only 15 seconds. It is 10 seconds shorter than the precise type measurement. With longer displayed hands' movement images, many subjects succeed to keep their hands synchronizing to the displayed hands' movements. With some error measurements' cycles, we can have enough valid measurements. Therefore, we have a large success ratio of trials.

B. Experiment

1) People in primary school ages

We obtained about 400 trials with whole pupils in a normal public primary school in Japan. Their ages span from 7 years old to 13 years old. The pupils with heavy healthy problems attend special support schools. Therefore, the pupils in a normal primary school are healthy. The pupils in a first grade in a primary school have difficulties to follow the instructions of the precise type measurement. The precise type measurement needs 1.7 times as much time as the simple type measurement. We cannot withstand this increase of measurement time. The measurement type must be the simple one.

2) Hight school Students

There are 35 subjects. However, there are many error trials. We have 24 valid measurements. They are third grade of high school. They are 17 or 18 years old. They are 21 male students and 3 female students. The authors made VST trials for the high-school students in voluntary basis. Therefore, the authors selected the simple type measurements.

3) Young people (University Students)

We obtained 232 trials with five healthy male students, with ages between 22 - 24 years old. The measurement type is the precise one.

4) Manhood people

We performed experiments with manhood people. They are 3 females and 12 males. They are from 25 years old to 63 years old. Their average age is 44 years old. They are all healthy. They made 168 trials. The measurement type is the simple one.

5) Elderly people

We performed experiments with elderly people, 75 years old in average. They are from 66 years old to be 82 years old. They are all healthy in their ages. In our observation, one female has a difficulty about walking. Therefore, we have 14 healthy elderly people, 4 males and 10 females.

The measurement type is precise one. Each person made two trials. Therefore, we have the 28 trials. One trial had a failure in measurement. We obtained 27 valid measurements of the trials.

6) Performance measure for a trial

a) Precise type measurement

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 at each cycle. The phase represents the difference of the timing between the proposed example motion and the motion made by a subject.

In a single cycle, 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. In addition, 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.

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

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

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

$$\mathrm{NSMTp} = \min(NSMHp_L, NSMHp_R) \quad (3)$$

In (3), NSMTp is the performance measure in a trial. $NSMHp_L$ is the NSMHp of the left hand. $NSMHp_R$ is the NSMHp of the right hand. This NSMTp represents the performance of a subject in a trial. Our previous experiments show that the difference between both hands is small. However, we select a better one for the measure of motor control function. A subject shows a difference of the performance between a left hand and a right hand. This paper uses the better performance.

b) Simple type measurements

At each simple type measurement, there are 15 cycles of hands' movements. At this type of measurement, the author uses all 15 cycles to estimate the performance.

Equation (4) defines the performance of a hand in a trial.

$$\mathrm{NSMHs} = \min_{i=1,13} average(NSM_i, NSM_{i+1}, NSM_{i+2}) \quad (4)$$

NSMHs 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.

$$\mathrm{NSMTs} = \min(NSMHs_L, NSMHs_R) \qquad (5)$$

In (5), NSMTs is the performance measure in a trial. $NSMHs_L$ is the NSMHs of the left hand. $NSMHs_R$ is the NSMHs of the right hand. The NSMTs represents the performance of a subject in a trial. However, we select a better one for the measure of motor control function. A subject shows a difference of the performance between a left hand and a right hand. This paper uses the better performance.

There is a difference between the definition of NSMTp and the definition of NSMTs. However, in most trials, around fifth cycle, both of NSMHs and NSMHp show the least value. Therefore, we can treat NSMTp and NSMTs in a same manner. In the precise type measurements, we have multiple measurements of a subject. The precise measurements are well controlled.

IV. RESULT AND DISCUSSIONS

A. NSMs

1) Pupil in Primary school

The rotation of hands can be achieved from the five years old. In Japan, pupils in primary school are from six years old to twelve years old. In these ages, the performance of a brain represented as motor control function are developing. The authors have a chance to measure the NSMs of all pupils in a primary school.

We summarize the measurements with subjects' age. Fig. 5 shows the distribution of all measurements in a primary school. In Fig. 5, x-axis is the months from birth. The y-axis is NSMTs. A linear approximation of the distribution is shown (6).

Table I shows the averages and the standard derivations in each school year. With the progress of school year, the average NSMTs decreases. We can estimate linear approximation of the distribution. (6) shows the linear approximation. In a month, a pupil in a primary school shows 0.0021 decrease of NSMTs.

$$\mathrm{NSMT} = -0.0021\mathrm{M} + 0.539 \qquad (6)$$

In (6), M is the month from birth of a subject.

The difference of 0.0021 is difficult to be measured. However, VST can distinguish the change of 0.002 NSMT. VST can measure the development in three months.

Table I. MEAN AND STD OF NSMTS AT EACH SCHOOL YEAR IN A PRIMARY SCHOOL.

School year	Average	STD
1	0.501	0.353
2	0.381	0.122
3	0.348	0.117
4	0.301	0.064
5	0.297	0.065
6	0.273	0.063

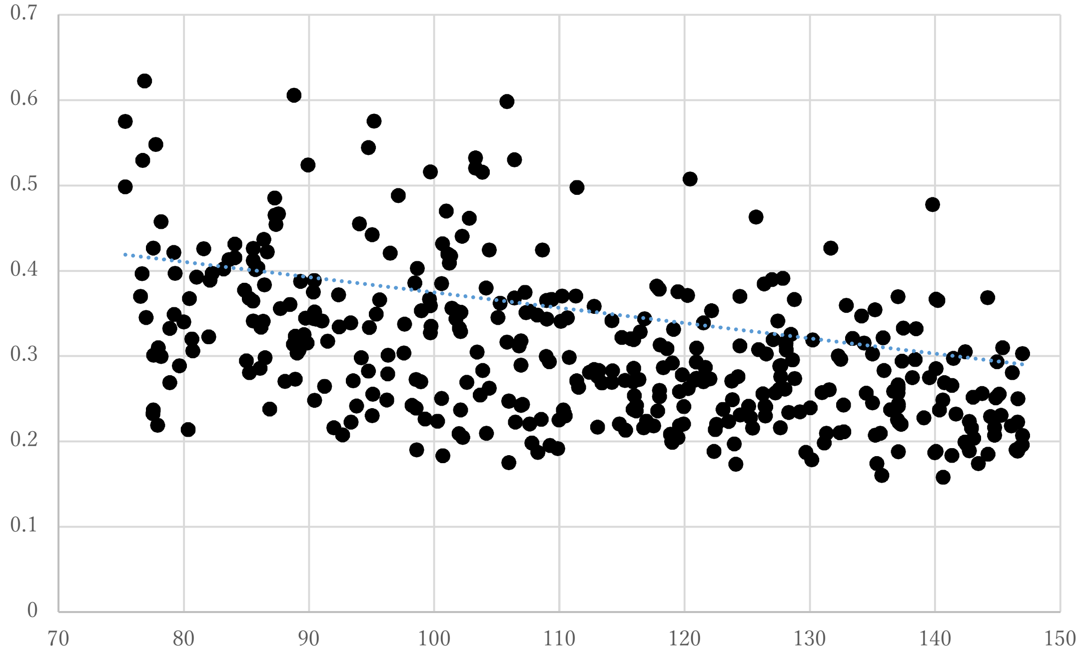

Figure 5. Age-NSMT Relation of Pupils in a primary school.

In the range from seven years old to 13 years old, (7) represents the estimated developmental age of pupils.

$$\mathrm{M} = -\frac{\mathrm{NSMT}}{0.0021} + 257 \qquad (7)$$

In (7), M is the estimated developmental age by months from birth.

There is a large number of subjects of pupils in a primary school. We can estimate the quadratic approximation of the distribution. (8) is the quadratic approximation of the distribution of all subjects in a primary school.

$$\mathrm{NSMT} = 0.00001145M^2 - 0.004658M + .6781 \qquad (8)$$

(8) estimates the distribution of NSMT from 75 months old to 147 months old. If we assume that the tendency represented in (8) continues, the development takes the peak at 17 years old. It is difficult to conclude that the performance of motor control function measured by VST takes its peak at 17 years old. However, this represents the tendency of slowdown of the development of our motor control function.

2) Students in high schools

In Japan, students in a high school are from 15 years old to 18 years old. However, all subjects in this category are 17 or 18 years old. Fig. 6 shows the distribution of all trials. In fig. 6, x-axis represents subject id and y-axis does NSMT. The average NSMT is 0.251.

Using (8), the estimated age of the 0.251 of NSMT is 139 months. Using (7), the estimated age of the 0.251 of NSMT is 137 months. This is same as the sixth grade of a primary school. The total measurements in a primary school and the measurements of 31 high-school students concludes that the motor control function of our brain completes its development at 12 years old. Of course, there are wide personal derivations.

3) Comparison between Primary Pupils and High School Students

This paper has no subject in a junior high school. The range of ages in junior high school in Japan is from 13 years old to 15 years old. This paper compares the last grade of a primary school and the high school students. In the last grade, we have 66 subjects. However, four measurements have to many errors. Therefore, we reject four measurements, and we have 62 valid measurements in the last grade in a primary school. We have 31 valid measurements of high school students. Table II shows the result of t-test between the pupils in sixth grade of a primary school and the students of high schools. The NSMT of pupils is larger than the one of high schools. However, the probability of both-side in the t-test is 0.26. Therefore, the t-test shows no difference of distributions. The number of subjects in this group is small. We must have much larger scale of measurements of VST.

4) Young people (University Students)

There are 231 trials. However, there are 18 error measurements. As a result, we have 213 valid measurements. Table III 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 the cycle 11, the example hands image disappears. The NSM at the cycle 11 increases a little. The differences among cycles are small. Fig. 7 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 proposed example motion shown in Fig. 7. After five seconds, there is a little loss in motion precision.

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

We confirm that they have the same distributions using t-test. Table IV shows the probability of sameness of the distributions from the one of the cycle 10. Fig. 8 shows the probabilities. From cycle 13 to cycle 19, the probabilities are decreasing. This shows that the short-term memory of motor

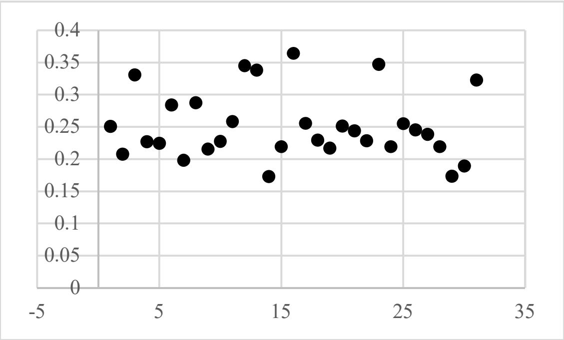

Figure 6. Distribution of NSMTs of High school students.

TABLE II. T-TEST BETWEEN NSMTS OF PRIMARY SCHOOL'S SIXTH GRADE AND HIGH SCHOOL

	6th grade	High school
Average	0.264074945	0.251265719
Distribution	0.002604565	0.002719835
#samples	62	31
Freedom	59	
t	1.124543755	
P(T<=t)	0.132668386	
t	1.671093032	
P(T<=t) Both	0.265336772	
t both	2.000995378	

function decrease rapidly. After cycle 20, the subjects lost the memory about the motion, and their hands' motions became more randomly.

With NSMTs, we estimate the performance of the younger people in synchronizing their hands' movement to the displayed hands' movement. Fig. 9 shows the total distribution of NSMTs in all trials. In Fig. 9, the x-axis represents the trial number. The y-axis is a NSMT. In average, NSMT is 0.217, and the standard derivation is 0.0321. Fig. 10 shows the distribution of NSMTs of younger subjects. The NSMTs concentrate around 0.2. Young men show their peak of physical development in twenties [17].

TABLE III. 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

TABLE IV. 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

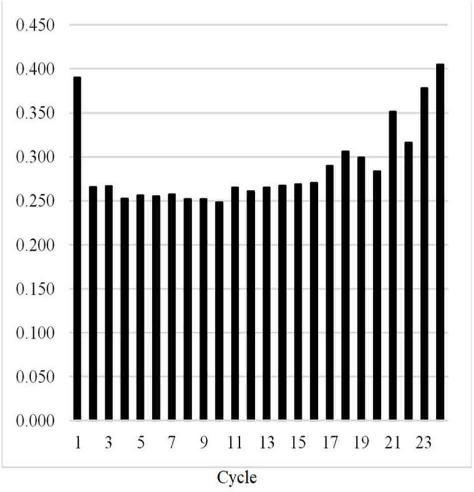

Figure 7. NSMs of each cycle in young people.

5) *Comparison between high school students and young people*

Between the distribution of NSMTs of high school students and the one of the young people, t-test shows the result of Table V. The both-side probability is only 0.004. There is a difference between the result of t-test confirms that the distribution of NSMTs of high school students and the one of young people. The performance of brain function estimated from the VST increases from 18 years old to 24 years old. However, the number of subjects of primary school ages are large and nearly complete in a region. The number of subjects of high school ages are small and selected from total ager's assemblage. The subjects of young people are also selected from total ager's assemblage. The young people are students

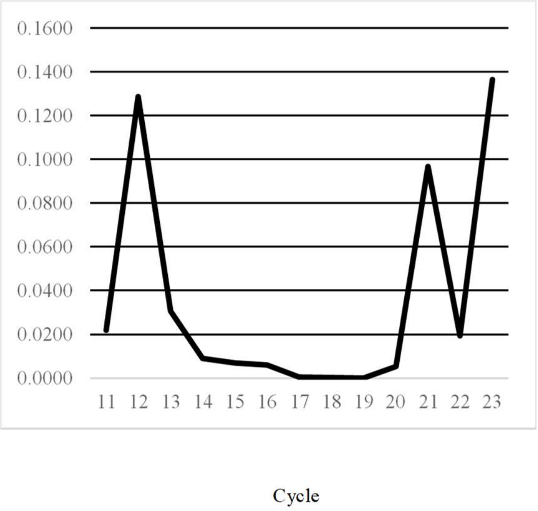

Figure 8. Probabilities of the sameness of the NSMs distributions to the cycle 10.

TABLE V. T-TEST BETWEEN HIGH SCHOOL STUDENTS AND YOUNG PEOPLE.

	High school	Young
Average	0.25684	0.218143
Distribution	0.004508	0.000902
#samples	31	68
Freedom	36	
t	3.071974	
P(T<=t)	0.002018	
t	1.688298	
P(T<=t) Both	0.004036	
t both	2.028094	

of a university. Therefore, the intellectual abilities of our subjects of the young people are better than one of total ager's assemblage.

The difference between high school ages and young people may represent the difference of their brain performance between different populations.

The decrease of NSMT per month is 0.000645 from high school to young people. This is under one-third of the rate of primary school subjects.

In many fields, developments of human functions show growth curve type. The development of brain function measured with VST must show the growth curve also.

6) Comparison between primary school pupil and young people

There is about 10-years difference between sixth grade of a primary school and young people. Table VI shows the result of t-test between 6th grade of a primary school and young people. The t-test confirms that the distribution of 6th grade of a primary school differs from one of the young people.

Using (2), 0.217 of NSMT leads 153.7 months from birth as the estimated age. This is one-year difference from the 6th grade of a primary school. This confirms that the motor control function of our brain slowdown its development over 12 years old.

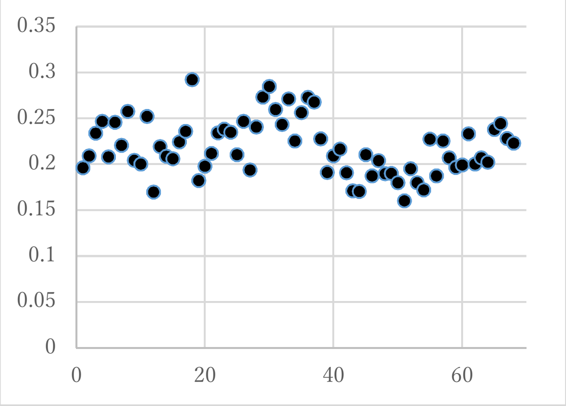

Figure 9. Distribution of NSMTs of Young People.

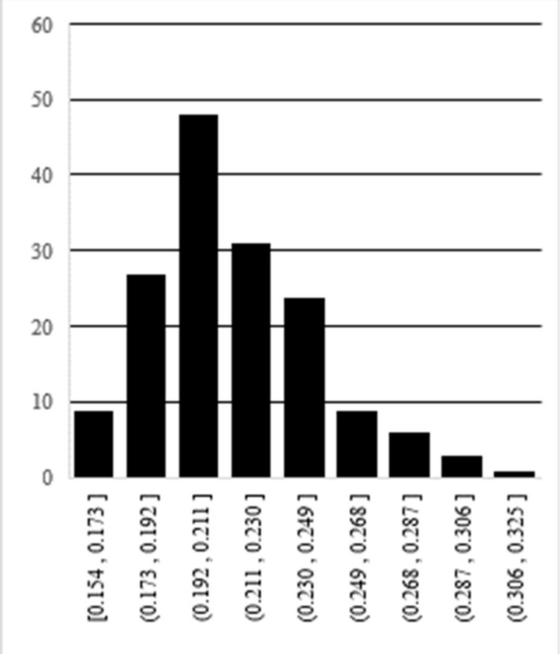

Figure 10. Distribution of NSMTs of young people.

7) Manhood people

Fig. 11 shows the distribution of measurements of all trials. In fig. 11, x-axis is the age of a subject and y-axis is the NSMT. We cannot find the relation between age and NSMTs. The average NSMT is 0.31886. In the distribution, there are some error measurements. Therefore, the author rejects the measurements over 0.6 NSMTs. Over 0.6 NSMT, subjects have some healthy problems. In the case, the average of under 0.6 NSMTs is 0.296. This is also a little worth than the students of high schools. The number of subjects is not large enough to estimate the change of the performance of VST with aging.

With stability in standing posture, we can find the effect of aging after 60 years old [18]. The result of this paper shows same tendency.

8) Elderly people

Table VII 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 the cycle 11, the displayed example hands image disappears. The NSM increases from cycle 11 to cycle 14. The differences between cycles are not large. Fig. 12 shows the average of NSMs in each cycle.

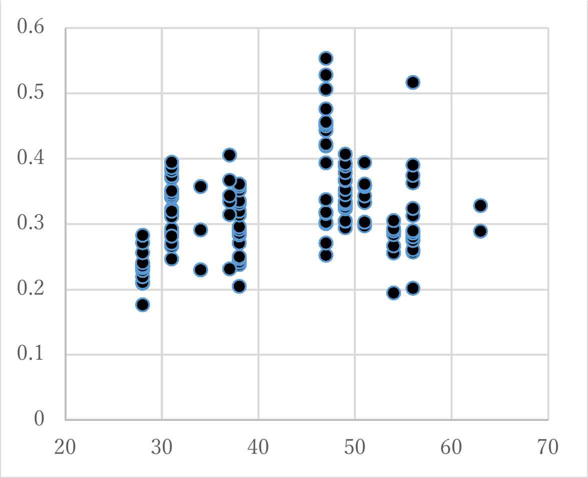

Figure 11. Age-NSMT relation of Manhood people.

Table VI. T-TEST BETWEEN NSMTS OF 6TH GRADE AND YOUNG PEOPLES

	6th grade	Young
Average	0.246935	0.218143
Distribution	0.002862	0.000902
#samples	70	68
Freedom	109	
t	3.912838	
P(T<=t)	7.95E-05	
t	1.658953	
P(T<=t) Both	0.000159	
t both	1.981967	

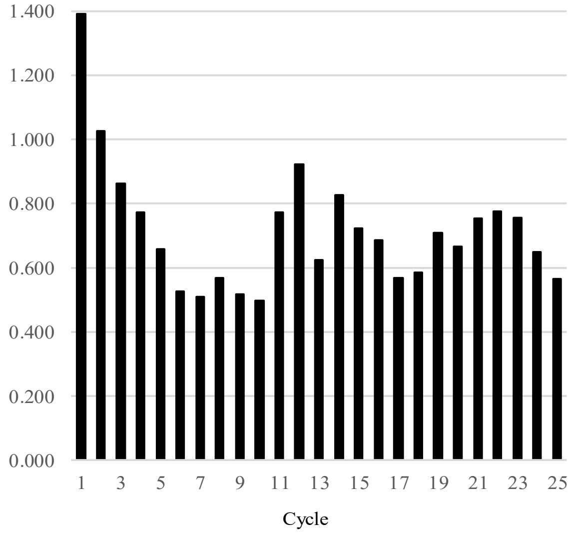

Figure 12. NSMs in each cycle on elderly people.

TABLE VII. 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

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 make t-test with these two groups of NSMTs. Table VIII 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 because of the aging process. There is an apparent difference between NSMs of young people and ones of elderly people, as shown in Fig. 7 and Fig. 12.

In elderly people, the deterioration of motor control function increases with the aging process. Fig. 13 shows the relation between the age and the NSMT of each elderly person. The correlation coefficient between the age and the NSMT of

TABLE VIII. T-TEST BETWEEN NSMTS OF YOUNG AND ELDERLY PEOPLE

	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	

elderly people is 0.467. There is a linear relation between the age and the NSMT. The linear approximation is (9).

$$\mathrm{NSMT} = 0.0088a - 0.26 \tag{9}$$

In (9), NSMT is the performance measure of motor control function. a is the years from birth of a subject. The age ranges from 66 years old to 83 years old.

From (9), we have (10) that estimates the age from NSMT.

$$\mathrm{NSMA} = 114\mathrm{NSMT} + 29.5 \tag{10}$$

In (10), 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.

The average of NSMTs is about 0.22 in young people. If the deterioration of motor control function shows a linear relation with the years from birth of a subject from the start of the deterioration, we can estimate the motor control function age with (10) over 53 years old people.

The average of NSMTs is about 0.30 in manhood people. If the deterioration of motor control function shows a linear relation. From (10), we have 63.7 years old as the age starting the deterioration with aging process. About 64 years old agrees the starting age of deterioration of aging discussed in [18].

9) Comparison between manhood people and elderly people

The average NSMT of manhood people is 0.296. With (10), the 0.296 of NSMT relates to the estimated age 63.2 years old. Of course, the number of subjects is not enough. The estimation of the starting point of aging is not 63 years old. There are some personal differences of NSMT. Using the normal distribution of NSMTs in manhood people, we have the distribution of starting point of aging. The distribution of manhood people is 0.0632. This leads seven years' distribution from the average 63.2 years old. The effects of aging about VST start from 56 years old to 70 years old. Therefore, we need much more subjects in this range of aging.

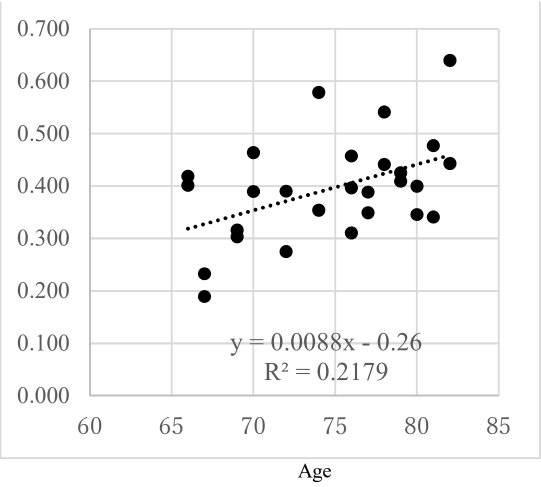

Figure 13. Age-NSMTs relation of elderly people.

10) Total tendency of development and deterioration with aging

From the age of a primary school to elderly people, the outline of the development of motor control function and the deterioration is observed from many experiments shown before. We can summarize the experiments into a total view of development and deterioration of motor control function measured with VST. Fig. 14 shows the total tendency. In Fig. 14, some parts do not relate the ages of subjects. However, they are high school students and young people. High school students are 18 years old. The young peoples are from 22 to 24 years old. The average of the ages of young people is 23 years old.

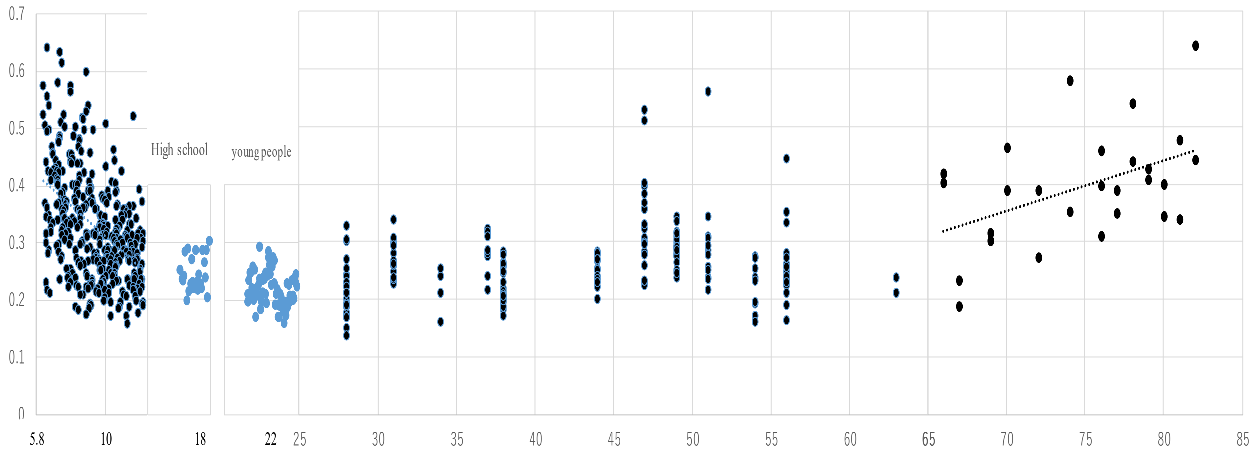

Figure 14. Total tendency of development and deterioration with aging.

In Fig. 14, x-axis is the age of a subject or the average ages of the subjects' group. In the figure, the range of manhood includes small number of subjects. However, the total view of Fig. 14 shows the outline of the development and the deterioration of the performance measured with VST.

Fig. 14 clearly shows the development and the deterioration with aging. Over 65 years old, a subjects show the NSMT under 0.2. These subjects keep their performance of motor control function in their ages.

In Fig. 14, we can see the outline of the development and the deterioration of a motor control function measured by VST. The tendency shown in Fig. 14 agrees the tendency of development in [17] and the tendency of deterioration of aging in [18].

B. *Phases*

The phase of the measured motion represents the timing of motion. In precise measurements, phases show 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.

There is no precise measurement about subjects in a primary school and manhood people.

1) *Pupil in Primary school*

In a primary school, we have only simple type measurements. In simple type measurement, we cannot have the phase change after the displayed hands' images disappeared. However, we can have the phase stability.

Table IX shows the average phase change between adjacent cycles. Fig. 15 shows the average phase changes of first grade, third grade and sixth grade. In Fig. 15, full line represents the first grade in a primary school. A chain line does the third grade. And, another line does the sixth grade. In Fig. 15, there is an apparent decrease of the average phase changes between adjacent cycles with growth. The phase changes between adjacent cycles decrease with getting older. In Table IX, we can find the development of motor control function. However, phases in VST have large distributions among subjects. Therefore, personal analysis of a subject is difficult.

Fig. 16 shows the average phase changes among grades in a primary school. We can see an apparent progress of motor control function with getting older in Fig. 16.

2) *High School Students*

High-school students made simple type measurements. Fig. 17 shows the phase changes of high-school students and the sixth grade of a primary school. In Fig. 17, the phase changes of high-school students is less than ones of sixth-grade pupils in a primary school. In averages, phase change of high-school students is 0.227. The average phase change of sixth-grade pupils in a primary school is 0.274. The average phase change of high-school student is 18% smaller than one of the sixth-grade pupils in a primary school. This shows the development of motor control function as NSMTs.

3) *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 starts from cycle 11, and ends at cycle 17. The third section starts from cycle 17, and ends at cycle 23, as shown in Fig. 4. In 158 valid trials, there are delay and advance in phases. We evaluate phase change in absolute value.

Table X 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.

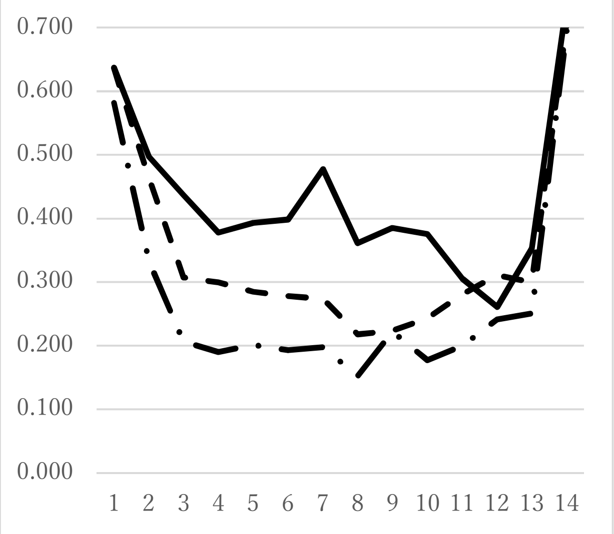

Figure 15. Average phase changes between adjacent cycles.

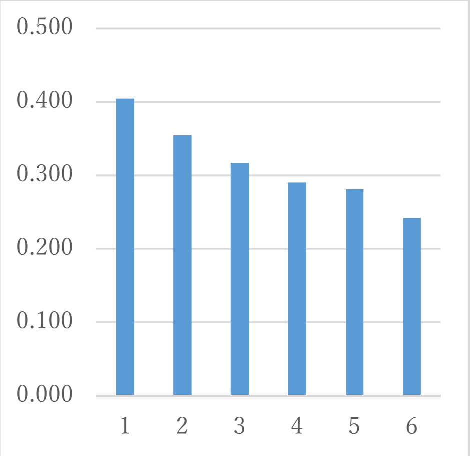

Figure 16. Average phase changes of each grade in a primary school.

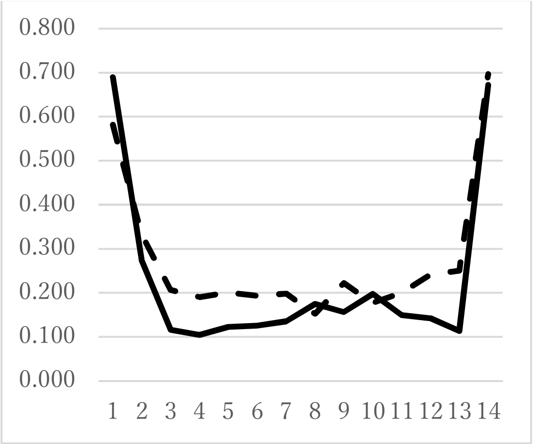

Figure 17. Average phase changes of high school students and sixth grade pupil of a primary school between adjacent cycles.

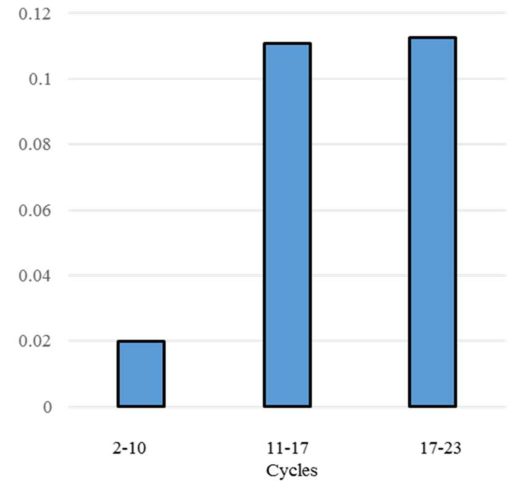

Figure 18. Phase changes in cycles.

Fig. 18 shows this relation. In Fig. 18, there is an apparent increase of phase changes in second and third 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.

4) Manhood peple

In manhood people, we have only the simple type measurements. Fig. 19 shows the average phase changes between adjacent cycles. In Fig. 19, the full line represents the average of manhood people. The dashed line does one of the high-school students.

The average of manhood people is larger than one of the high-school students. In average, the phase change is 0.272. This is nearly same as the average of sixth-grade pupil of a primary school. These are 20% larger than the average phase change of high-school students.

5) Elderly people

We also calculate the linear approximation of the phases. Table XI 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,

TABLE X. 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

Table IX. AVERAGE PHASE CHANGES BETWEEN ADJACENT CYCLES.

Cycle/ Grade	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.637	0.497	0.437	0.378	0.393	0.398	0.477	0.361	0.385	0.376	0.306	0.261	0.353	0.739
2	0.626	0.572	0.338	0.318	0.356	0.375	0.306	0.330	0.293	0.292	0.240	0.297	0.267	0.679
3	0.635	0.463	0.307	0.300	0.285	0.278	0.273	0.218	0.224	0.243	0.281	0.311	0.300	0.707
4	0.785	0.467	0.274	0.244	0.218	0.225	0.237	0.221	0.182	0.199	0.213	0.291	0.217	0.735
5	0.620	0.473	0.354	0.226	0.232	0.227	0.209	0.217	0.223	0.191	0.214	0.213	0.255	0.748
6	0.582	0.333	0.207	0.190	0.201	0.193	0.198	0.152	0.222	0.177	0.200	0.241	0.250	0.697

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 an 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.

TABLE XI. 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

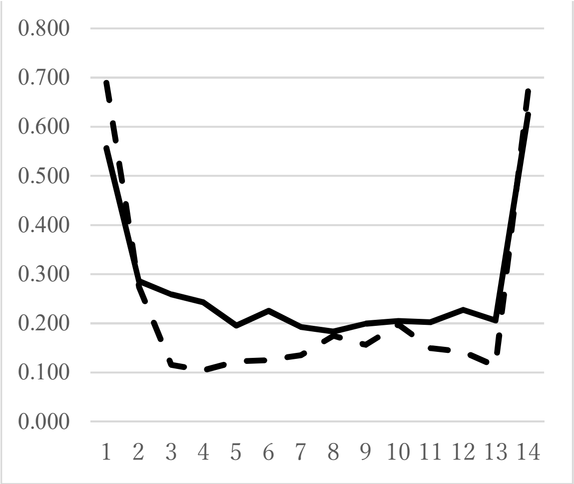

Figure 19. Average phase changes of high school student and Manhood people between adjacent cycles.

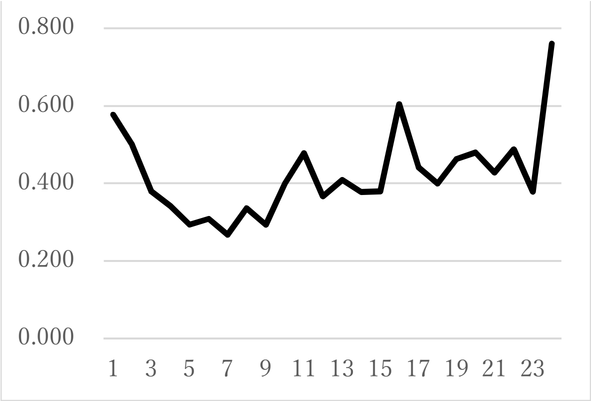

Figure 20. Average phase changes between adjacent cycles of elderly people.

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.

Fig. 20 shows the average phase change between adjacent cycles. Elderly peoples need seven cycles to synchronize their hands' movements to the displayed hands' movement. The average phase change between the third cycle and tenth cycle is 0.37. This is about 0.1 larger than one of the manhood people.

Elderly people has much difficulty about synchronizing his hands' movement to the displayed movement. The phase changes between adjacent cycles may have the role to evaluate the performance of motor control function. However, the phase change can have large dependency to the NSM. In the case, we can use only NSM.

V. CONCLUSION

This paper proposes the pair of the measurement and evaluation method of motor control function to estimate whole image of the development and the deterioration with an aging process. The proposed method is implemented and tested in experiments. The proposed visual synchronization task is easy to perform. For instance, it needs only 25 seconds. The 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 development and deterioration of a motor control function with an aging process precisely. This paper proposed the total view of the development and deterioration of the performance of motor control function from six years old to 80 years old, and developed a method to estimate the age according to the aging process of the motor control function in some age groups. In the age group over 65 years old, the estimated age from NSMT helps to measure the deterioration of the brain function, and it can detect the very first stage of cognitive impairment. In the age group in a primary school, the estimated age from NSMT may work for the index of developmental disorder.

Many experiments outlined the development and deterioration of the performance of motor control function with aging process. This helps the understanding of developments and deteriorations of brain function with aging process.

We will perform larger-scale experiments in the next step for more precise understanding of developments and deteriorations with aging process.

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REFERENCES

[1] K. Aoki and H. Hotta, “Aging Measurements with Precise Observations of Synchronization Hands’ Movements -Aging effects about motor control function-,” Global Health 2016, pp. 49-55, October 9 - 13, 2016, Venice, Italy, IARIA, ISBN: 978-1-61208-511-1, 2016.

[2] Lafayette Instrument, “Purdue Pegboard Test,” http://www.lafayetteevaluation.com/product_detail.asp?ItemID=159, retrieved 2016/08/29.

[3] S. Hirata, Y. Kitajima, T. Hosobuchi, and M. Kokubun, “The speed and accuracy of fine motor actions in children with intellectual disabilities,” Bulletin of Tokyo Gakugei University, 59, pp. 263-267, 2008.

[4] M. Kokubun, “Are children with down syndrome less careful in performing a tray-carrying task than children with other types of mental retardation?” Perceptual and Motor Skills, 88:3c, pp. 1173-1176, 1999.

[5] M. J. Hove, J. R. Iversen, A. Zhang, and B. H. Repp, “Synchronization with competing visual and auditory rhythms:bouncing ball meets metronome,” Psychological Research, 77, pp. 388-398, 2013.

[6] Y. Sugano, M. Keetels, and J. Vroomen, “The Build-Up and Transfer of Sensorimotor Temporal Recalibration Measured via a Synchronization Task,” Front Psychol. 2012; 3: 246, doi:10.3389/fpsyg.2012.00246, 2012.

[7] V. Krause, B. Pollok, and A. Schnitzler, “Perception in action: The impact of sensory information on sensorimotor synchronization in musicians and non-musicians,” Acta Psychologica, Volume 133, Issue 1, pp. 28-37, January 2010.

[8] J. Lee, J. Chai, and P. S. A. Reitsma, “Interactive Control of Avatars Animated with Human Motion Data,” ACM Transactions on Graphics (TOG). ACM pp. 491-500, 2002.

[9] S. Vercruysse, J. Spildooren, E. Heremans, J. Vandenbossche, O. Levin, N. Wenderoth, S. P. Swinnen, L. Janssens, W. Vandenberghe, and A. Nieuwboer, “Freezing in Parkinson's disease: a spatiotemporal motor disorder beyond gait,” Movement Disorders, 27(2), pp. 254-263, 2012

[10] M. A. Smith, J. Brandt, and R. Shadmehr, “Motor disorder in Huntington's disease begins as a dysfunction in error feedback control,” Nature, 403, pp. 544-549, 3 February 2000.

[11] K. Rubia, A. B. Smith, M. J. Brammer, B. Toone, and E. Taylor, “Abnormal Brain Activation During Inhibition and Error Detection in Medication-Naïve Adolescents with ADHD,” Am Psychiatric Assoc., 162, 6, pp. 1067-1075, June 2005.

[12] Microsoft, “Kinect for Windows,” https://www.microsoft.com/en-us/kinectforwindows/, retrieved 2015/07/07.

[13] Leap Motion, “Leap Motion SDK,” https://developer.leapmotion.com/, retrieved at 2015/03/17.

[14] Microsoftstore, “Kinect,” http://www.microsoftstore.com/store/msusa/en_US/list/Kinect/categoryID.64752700, retrieved at 2015/07/08.

[15] K. Aoki, and H. Hotta, “Brain Activity Estimation with Precise Motor Measurements of Visual Synchronization Task of Hands,” 2015, Global Health 2015, pp.39-44, ISBN: 978-1-61208-424-4, ISSN: 2308-4553, Nice, France, July 2015.

[16] P. Duhamel and M. Vetterli, "Fast Fourier transforms: a tutorial review and a state of the art," Signal Processing, vol. 19, pp. 259-299, Apr. 1990.

[17] Y. Yamada, M. Kimura, E Nakamura, Y. Masuo, and S. Oda, “Limb muscle mass decrease with aging in Japanese men and women aged 15-97 yr,” The Japanese Journal of Physical Fitness and Sports Medicine, Vol. 56, 5, pp. 461-472, 2007.

[18] K. Hashizume, H. Ito, H. Maruyama, H. Saito and M. Ishikawa, “Age-Related Changes of Stability in Standing Posture,” Journal of the Japan Geriatrics Society, Vol. 23, 1, pp. 85-92, 1986.