34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Aging Curve of Neuromotor Function by Pronation and Supination of Forearms using Three-dimensional Wireless Acceleration and Angular Velocity Sensors *

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Abstract—**We have developed an evaluation system for pronation and supination of forearms. The motion of pronation and supination of the forearm is used as a diagnosis method of developmental disability, etc. However, this diagnosis method has a demerit in which diagnosis results between doctors are not consistent. It is hoped that a more quantitative and simple evaluation method is established. Moreover it is hoped a diagnostic criteria obtained from healthy subjects can be established to diagnose developmental disorder patients. We developed a simple and portable evaluation system for pronation and supination of forearms. Three-dimensional wireless acceleration and angular velocity sensors are used for this system. In this study, pronation and supination of forearms of 570 subjects (subjects aged 6-12, 21-100) were examined. We could obtain aging curves in the neuromotor function of pronation and supination. These aging curves obtained by our developed system, has the potential to become diagnostic criteria for a developmental disability, etc.**

I. Introduction

Pronation and supination of the forearms involves movements to bend the elbow to 90 degrees, and to rotate the palm and the back of the hand. This motion is one of many diagnostic tests of soft neurological signs. Other examples are convergence, heel gait and finger to nose tests. Soft neurological signs are used as diagnosis method for developmental disability. Medical doctors observe the regularity of a patient's motion and dexterity by the motion of pronation and supination. When this motion is monitored, it is possible to examine neuromotor development. There are various studies related to developmental disability and soft neurological signs [1-5]. However, this diagnosis method has a demerit in which the diagnosis results between doctors are not consistent. It is hoped that a more objective and simple evaluation method can be established. Moreover it is hoped diagnostic criteria obtained from healthy subjects can be established to diagnose developmental disorder patients. We focused on pronation and supination which are simple motions in soft neurological signs and developed a simple evaluation system for pronation and supination[6]. Three-dimensional wireless acceleration and angular velocity sensors are used for this system. Our developed system is a simple and easy evaluation system for the motion of pronation and supination. In a previous paper, we compared pronation and supination of normal developing children (subject aged 6-11) with pronation and supination of developmental disability children using our developed evaluation system [7]. The purpose of this paper is to obtain more accurate diagnostic criteria. Therefore we increased the subject size and examined 570 subjects (subjects aged 6-12, 21-100). We could obtain aging curves of the neuromotor function from the measured results. We conclude that aging curves obtained by our developed system has the potential to become diagnostic criteria for evaluation of a developmental disability.

*Manuscript received April 17, 2011. This work was supported in parts by Grant-in Aids for Scientific Research, Ministry of Education, Science, Sports, Culture and Technology, Japan (No.21300168, No.23650267), Kakihara Science and Technology Foundation.

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II. Evaluation System of Pronation and Supination

A. System Configuration

Fig.1 shows the developed evaluation system that we used for the motion of pronation and supination. This system consisted of four three-dimensional wireless acceleration and angular velocity sensors (WAA-006, ATR-Promotions), a guide monitor, a charge-coupled device camera (CCD camera) and a notebook computer. The four sensors were attached to the limbs of the subject, with one sensor on each respective hand and one sensor on each respective elbow. Signals were transmitted by blue tooth to the notebook PC. The notebook PC was used for the data acquisition. The subjects imitated motion from a demonstration guide that was displayed on a monitor. The motion of the subject was recorded by the CCD camera.

B. Data Analysis

Fig.2 shows the waveforms of the three-dimensional acceleration and angular velocity, along with measurement coordinate system of pronosupination. The sampling frequency is 1 kHz. The low pass filter is 4Hz. We have three indices to evaluate the subject's motion, obtained from the acceleration and angular velocity sensors. These indices are accuracy, stability and cooperativeness. Firstly, accuracy is an index of correlation between the subject's motion and instructed motion. Secondly, stability is an index of motion of hands and arms.

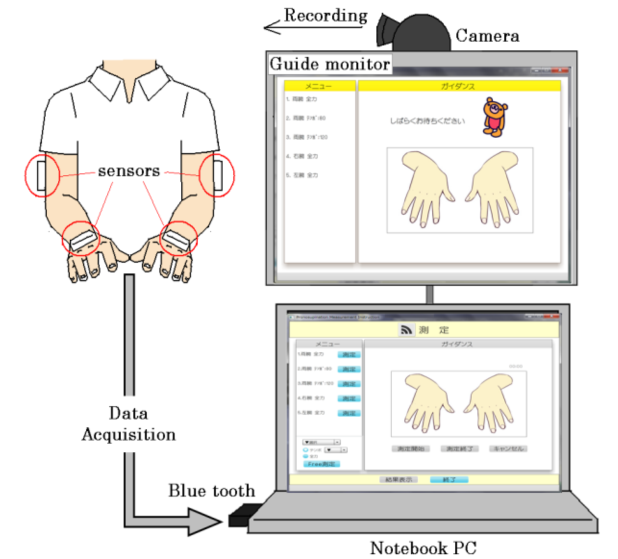

Figure 1. The measurement system of pronosupination and coordinate of the acceleration and angular velocity

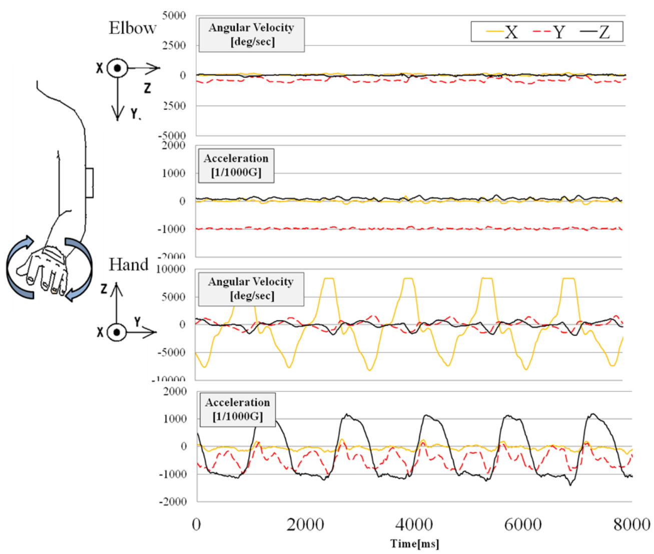

Figure 2. The Waveforms of acceleration in three-directions and of angular velocity in three directions

Thirdly, cooperativeness is an index of precision of symmetrical movement between left hand and right hand. Moreover, these three indices have parameters to calculate index scores evaluating the subject's motion. Parameters of accuracy include the following three kinds of parameters:

- The difference in time between the trigger time and 0 crossing point time of angular velocity on the X direction (both hands)
- Dispersion of continuous FFT peak frequency of angular velocity on X directions (both hands)
- Dispersion of continuous FFT peak frequency power of acceleration on Z directions (both hands)

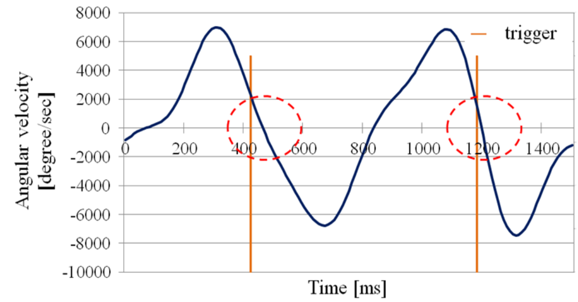

Figure 3. A parameter of accuracy is difference of time between angular velocity on X directions and a trigger

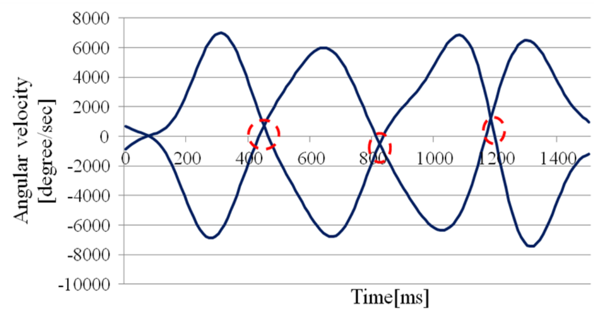

Figure 4. Asynchronous time of angular velocity on X directions between right hand and left hand

Fig.3 shows the difference in time between the trigger time and 0 crossing point time of angular velocity on the X direction. The orange line is a trigger. A trigger indicates the basic position of instructed motion. Red circles show parts of the difference in time between angular velocity on X directions and a trigger. A parameter of stability is as follows:

- The average (or dispersion) of maximum (or minimum) acceleration on X direction (both hands)

Parameters of cooperativeness include the following three kinds of parameters:

- The asynchronous time of angular velocity on X directions between right hand and left hand
- The correlation coefficient of angular velocity on the X direction between right hand and left hand
- The correlation coefficient of acceleration on the Z direction between right hand and left hand

In Fig.4, red circles show parts of the asynchronous time between the right hand and the left hand. If values of angular velocity for the right and left hands are both positive (negative) values, we consider time for this part to be asynchronous. Moreover, we measured healthy adults (aged 23-28) to calculate each index value. The average for healthy adults was 80 points. The score of each index is based on these values. The index score ranges from 0 to 100 points.

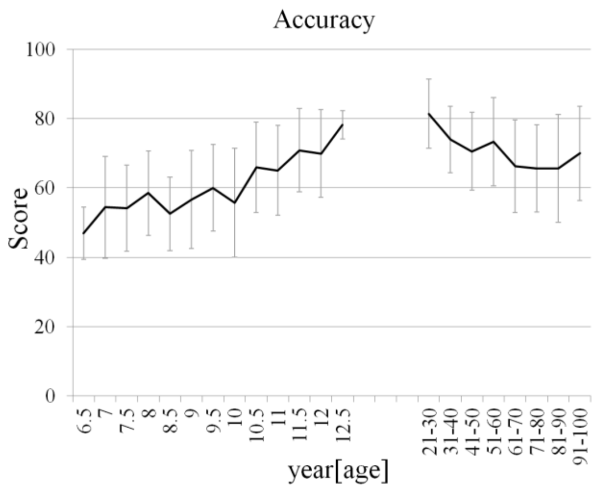

Figure 5. The aging curve of an accuracy of index scores for healthy subjects (subjects aged 6-12, 21-100)

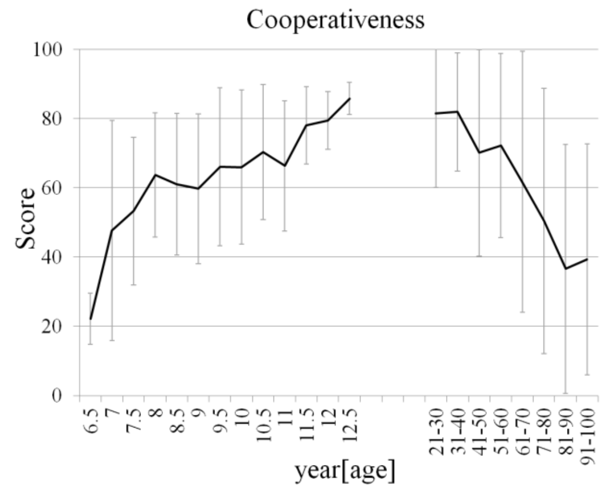

Figure 7. The aging curve of a cooperativeness of index values for healthy subjects (subjects aged 6-12, 21-100)

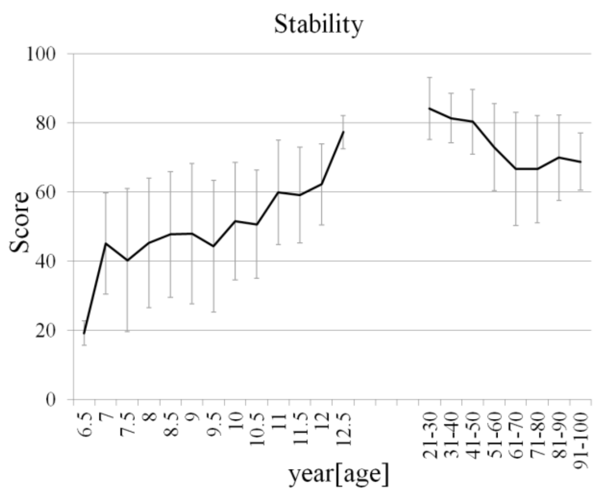

Figure 6. A The aging curve of a stability of index scores for healthy subjects (subjects aged 6-12, 21-100)

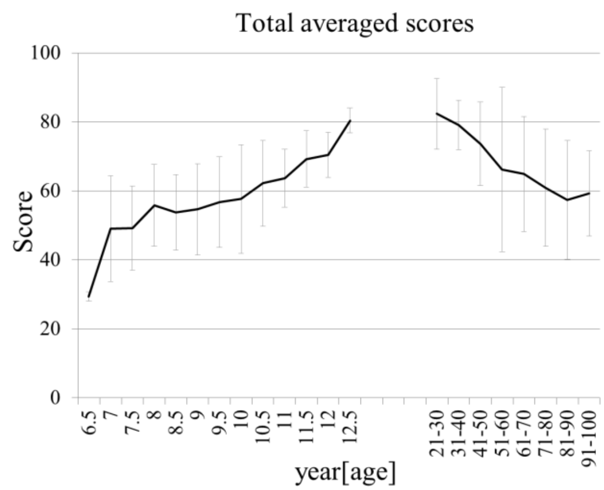

Figure 8. The aging curve of total averaged scores of the three indices for healthy subjects (subjects aged 6-12, 21-100)

III. MEASUREMENT

We measured the motion of pronation and supination of the forearm of 570 healthy subjects (subjects aged 6-12, 21-100) to obtain a diagnosis criteria. Before starting the measurement, all subjects received an explanation of the purpose of study, procedures and hazards of measurement. All subjects agreed to participate. The subject stood in front of a guide monitor and four acceleration and angular velocity sensors were attached to the back of both hands and both elbows as shown in Fig.1. The subject bent the elbow to 90 degrees and imitated the motions of the demonstration guide. The demonstration guide showed a motion that pronates and supinates both hands at the speed of 120 times a minute.

IV. RESULTS AND DISCUSSION

We measured the motion of pronation and supination of the forearm of 570 healthy subjects (subjects aged 6-12, 21-100) to obtain a diagnosis criteria. From the measurement, we could obtain aging curves of the neuromotor function for the motion of pronation and supination. Fig.5~7 show the aging curves of the neuromotor function for pronation and supination of the forearm. Fig.5 shows the aging curves of accuracy, which is an index of the correlation between the subject's motion and motion of the demonstration guide. Fig.6 shows the aging curves of stability, which is an index of the motion of hands and arms. Fig.7 shows the aging curves of cooperativeness, which is an index of precision of symmetrical movement between left hand and right hand. The horizontal axis represents age. In order to observe neuromotor function in relation to rapid growth, we evaluated scores of children between the ages of 6 and 12 at 6-months segments. In the horizontal axis, 7 means subjects from 7years and 1 month to 7 years and 6months. 7.5 means subjects from 7 years and 7 month to 7 years and 12 months. The vertical axis indicates the average of index score for healthy subjects. As shown in Fig.5~7, aging curves of neuromotor development

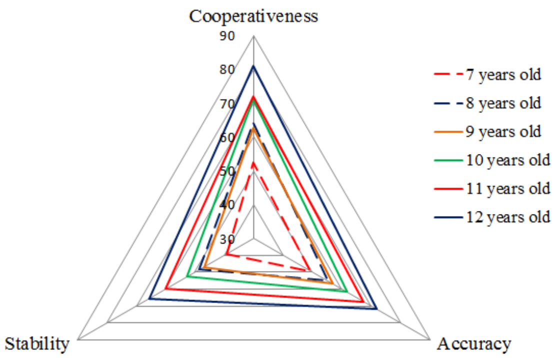

Figure 9. The radar chart of the average of children's indices scores (7-12 yeas old children)

have a tendency to increase between 6 and 12 years old as they grow older. Moreover, aging curves have a tendency to decrease between 21 and 70 years old in each index. From these results, it is inferred that these aging curves show growth and decline of neuromotor function for healthy subjects. Fig.8 shows the total averaged scores of the three indices. Total averaged scores are calculated from the average of accuracy, stability and cooperativeness. We could obtain more accurate aging curves by averaging these three indices. Moreover, as shown in Fig.9 and Fig.10, we used a radar chart to represent the balance of these three indices in neuromotor function for pronation and supination. In Fig.9, radar charts show the average from 7 year old children to 12 year old children respectively. The radar charts of children are well-balanced as they grow older. Change of stability is slows in comparison to other indices. In Fig.10, radar charts shows the average from 20's subjects to 90's subjects respectively. Radar charts between 20's and 30's do not show much change. The radar charts in 40's and over have a tendency to decrease as they grow older. In particular, there is substantial change in the cooperativeness. From these results, the radar charts of adults shows that the neuromotor function of subjects indicates a low performance as subjects grow older. We believe that aging curves obtained by our developed system has the potential to become diagnosis criteria for evaluation of a developmental disability. Moreover, pronation and supination of forearms can be used as diagnosis methods of cerebellar ataxia and other related disorders. We think that this system has the potential to also become the evaluation system for cerebellar ataxia. However, aging curves of stability leveled off between71 and 100 years. In 90 years old and over, aging curves of accuracy and cooperativeness increased as they grow older. This may be due to subjects of 71 and over who participated in this experiment were all of a vigorous nature and thus were not a true representation of the age group. In order to obtain a satisfactory result statistically, we have to collect more subjects and examine the parameters of three indices and tasks. In this study, we could obtain aging curves of the neuromotor function for healthy subjects (subjects aged 6-12, 21-100). In the future, we think that this system has the potential to become the evaluation system for a developmental disability and cerebellar ataxia.

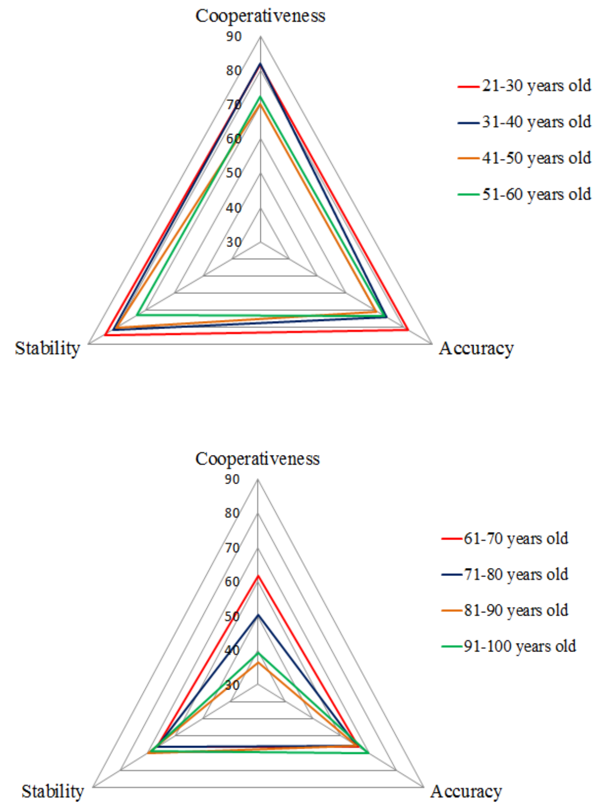

Figure 10. The radar chart of the average of adult's indices scores (21-60 years old subject (up) and 61-100 years old subjects)

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