Investigation of Voluntary Movements in Auditory Stimulated Conditions by Integrative Measurement

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Abstract: In general, voluntary movements can easily change from trial to trial. The reasons why are not clearly understood. We used an integrative biological information measurement and analysis system that we previously proposed to measure biological information during voluntary movements, especially handwriting, under auditory stimulation, and we considered the relationship between changes in voluntary movement and stimulation. Our findings will be applicable to rehabilitation, functional electrical stimulation, bio-feedback, and voluntary movement correction.

Keywords: **EMG, EEG, Handwritten Characters, Auditory Stimulation**

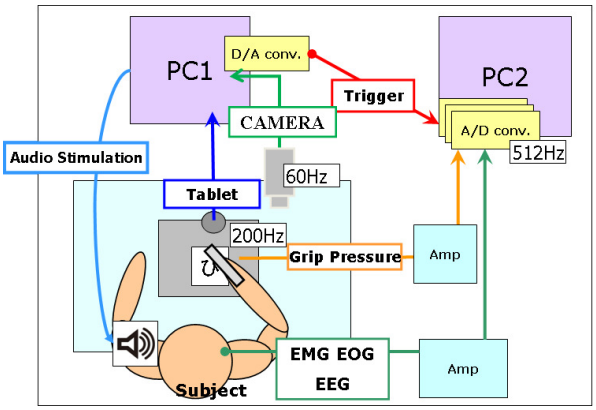

Fig. 1. Measurement system.

I. INTRODUCTION

Recently, studies on handwriting have been reported in many fields [1] [2]; however, there have been few studies examining character deformation [3]. In our earlier studies, we considered the relations between biological information, the shapes of handwritten characters, and their variations. We also developed an integrative measurement system for measuring and analyzing biological information and character shapes [4]. We used the same system in the present study reported here. The purpose of this study was to investigate the underlying relationships between stimulation and character deformation under auditory stimulation conditions, based on biological information, such as EMGs, EEGs and so on.

Ordinarily, handwriting is affected by various stimuli. During the handwriting process, we first receive stimulation from the external environment via our sensory organs, such as the eyes, ears, skin and so on. Then, when the stimulation reaches our brain via nerve conduction, our brain cannot continue the writing process with precision. As a result the handwriting is deformed.

The findings of this study are expected to find applications in functional electrical stimulation (FES), biofeedback, and so on. Biofeedback involves reporting invisible internal information of the body in a recognizable way, which usually means visually or aurally.

II. MEASUREMENT SYSTEM

Fig. 1 shows the measurement system developed in our earlier studies. It consists of five components: (1) a tablet, (2) three pressure sensors, (3) EMG, EOG, and EEG measurement systems, (4) a tracking system, and (5) an auditory stimulation presentation system. The sampling frequencies were different in each system. Therefore, an interpolating method was used to make the sampling rates conform to each other. In detail, biological information and grip pressure were acquired via the same A/D converter, whose sampling frequency was 512 Hz. The tablet's sampling frequency was limited to 200 Hz, and the camera's was limited to 60 Hz.

1. Character recognition system

The character recognition system used a tablet (WACOM Intuos 3 PTZ-930) for handwritten character recognition. The tablet could measure the location (X,Y) of the tip of a pen, the writing pressure, and the elevation and azimuth angles. The tablet was controlled by software, which also controlled the camera and the D/A converter for outputting a trigger signal for

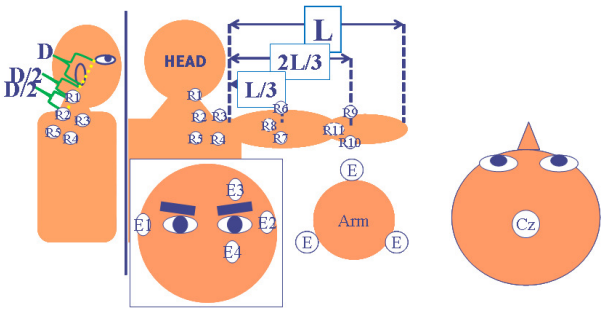

Fig. 2. EMG, EOG and EEG channels.

synchronization. The sampling frequency of the tablet was 200 Hz.

2. Pen grip pressure measurement system

The grip pressure was measured with three pressure sensors (Nitta Corporation: FlexiForce), placed on the pen to correspond to the thumb, the index finger, and the middle finger. The pressure measurement system was connected to the A/D converter on PC2, and the sampling frequency depended on the A/D converter, which was set to 512 Hz.

3. EMG EOG and EEG measurement system

In our early study, the number and positions of the EMG, EOG, and EEG measurement channels were defined as shown in Fig. 2. The number of EMG channels was 24, the number of EOG channels was 2, and the number of EEG channels was 1.

The sampling conditions are shown in Tables 1 and 2. A common sampling frequency of 512 Hz was used for the EMG, EOG, and EEG channels.

Table 1. EMG and EOG sampling conditions. (HFF: high frequency filter; LFF: low frequency filter)

HFF	30 Hz
LFF	1.5 Hz
Sense	50 μV
Ham Filter	50 Hz

Table 2. EEG sampling conditions.

HFF	50 Hz
LFF	0.01 Hz
Sense	50 μV
Ham filter	50 Hz

4. Real-time tracking system

The tracking system consisted of a CCD camera (Library Corp.: GE60) and software (based on Library Corp.: Radish SDK) to control the camera and provide a

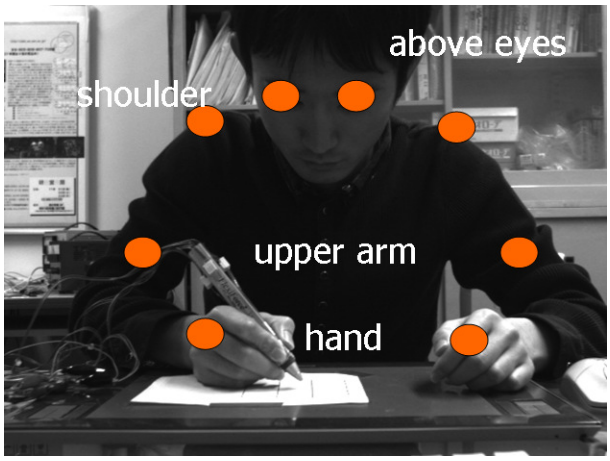

Fig. 3. Tracking points.

tracking function for tracking eight points, as shown in Fig. 3. The tracking points were the hands, upper arms, shoulders, and areas above the eyes, on both the left and right sides. The tracking results were recorded on PC1 as coordinate data (X, Y) with a trigger signal issued when the pen touched or was released from the tablet. The sampling frequency of 60 Hz was limited by the camera.

5. Stimulus Presentation System

Subjects were presented auditory stimulation, a 1000 Hz 50 ms-long tone, through noise-canceling headphones (Maxell: HP-NC22.OH-BK) from PC2. The headphones cancelled noise from 60 to 520 Hz, with a suppression level of about 22 dB down at 200 Hz.

6. Data Synchronization

All systems were synchronized by experimental software designed to control the tablet, the camera, and the D/A converter and to save the collected data. Data collected by the tablet was the character shapes (X,Y), writing pressure, and elevation and azimuth angles. The number of tracking points was limited to eight, and each data item had two dimensions. This software generated a trigger signal when the tablet detected a pen touch/release. The signal was +5 V when the pen touched and +2.5 V when the pen was released.

III. ANALYSIS

1. Classification

Before analysis, the measured data were classified into three groups: Group 1, just before the stimulated trial; Group 2, during the stimulated trial; and Group 3, just after the stimulated trial.

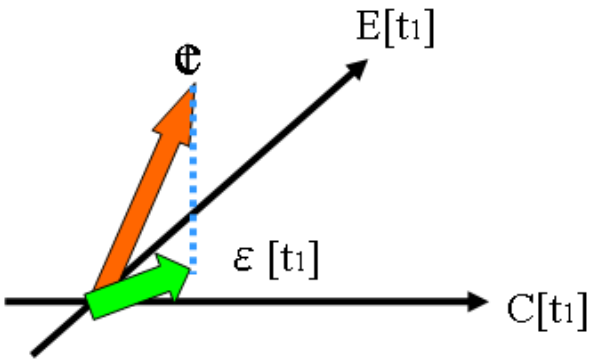

Fig. 4. Eigenvector Projection for ${}^{(i)}C_m$ - ${}^{(k)}E_m$, at t1.

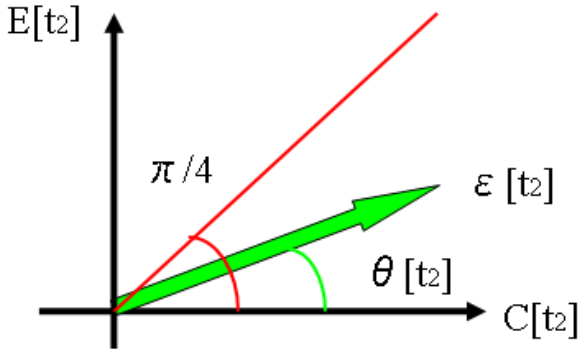

Fig. 5. Argument of the projected vector on C_m - E_m dimension, at t2.

2. Evaluation Processes

The evaluation method adopted in this study was based mainly on principal component analysis (PCA), which was developed in our earlier study. The evaluation process used in this study is described below.

First, preprocessing was executed. The EEG result was frequency analyzed to calculate the alpha wave, the beta wave, and the evoked wave that consisted of 1–30 Hz EEG. Then the original EEG data were replaced by the two sets of frequency-analyzed data. Next, measured character shapes were normalized based on their centers of gravity, and all data were normalized to 500 Hz for every trial. Three-dimensional spline interpolation, a well-known method, was used for upsampling.

Second, the measured and preprocessed data were defined as matrixes ${}^{(i)}C_m$ and ${}^{(k)}E_m$, where $i = (1,2), k = (1,2,\ldots,50)$, and m means the number of characters. Matrix C contained the character coordinates (X, Y), and matrix E contained 30 channels of biological information, 3 channels of data collected by the tablet, except for character coordinates, and 8 channels of X and Y tracking coordinates.

Third, ${}^{(i)}C_m$ and ${}^{(k)}E_m$ were used for PCA for each i and k. There were 100 patterns of the matrixes. By extracting only the first principal component from all the measured data, high correlation of the body position and character deformation was estimated with an evaluation function, P, defined as follows:

$$ {}^{(i)(k)}P_n[t] = \left| {}^{(i)(k)}\varepsilon_q[t] \right| \times \left(1 - \left| \frac{\frac{\pi}{4} - {}^{(i)(k)}\theta_q[t]}{\frac{\pi}{4}} \right| \right) \quad (1) $$

where i is the number of dimensions indicating the character location (X, Y), k is the number of measured channels, and q is the number of principal components. The term $\varepsilon_q[t]$ is the eigenvector $e_q[i,k]$ of the q-th principal component projected on the character information – other information dimension (C – E dimension). Therefore, if θ is $\pi/4$, the position of the body has a high correlation with the changes in the character shapes. ${}^{(i)(k)}P_n[t]$ exists over a range of 0 to 1. ${}^{(i)(k)}P_n[t]$ is a time-series evaluated value that indicates the correlation between changes in character shapes and each EMG channel. In detail, changes in the EMG indicate that a muscle moved. Therefore, the higher ${}^{(i)(k)}P_n[t]$, the higher the correlation between the channel and changes in character shapes.

Fourth, ${}^{(i)(k)}P_n[t]$, the evaluated value, for Group 1 and Group 2 were compared based on the coefficients of correlation. In detail, areas (periods) before and after the stimulated point for Groups 1 and 2 were compared. The area 400 ms before the stimulation was defined as area X, and the area 400 ms after the stimulation started was defined as area Y. If the character shapes were changed in response to the stimulation, the values of the coefficients should have changed after the stimulation, that is, area Y.

Therefore, two rules, Rule A and Rule B, were defined for evaluating the coefficients. For Rule A, the coefficient of correlation was Cx<-0.4, Cx>0.4 and -0.2<Cy<0.2. This corresponds to deformation caused by the stimulation. On the other hand, for Rule B, the coefficient of correlation was -0.2<Cx<0.2, and Cy<-0.4, and Cy>0.4. In other words, the changes in character shapes and biological information were small before the stimulation, whereas larger changes appeared after the stimulation. This is called the correction effect. In this study, because none of the channels satisfied rule B, only rule A was considered.

IV. EXPERIMENT

Subjects were required to write 20 *hiragana* (Japanese syllabary) characters "ひ" in about 1 second per character, and this was defined as one session. The auditory stimulation was presented randomly with a probability of 10%, and the experiment was conducted until the number of stimulated trials reached 90. To measure clear EEG signals, the experiment was performed in the afternoon, at least 2 hours after the subject's last meal. Three subjects participated in this study. The total number of measured and analyzed channels was 49: 24 EMGs, 1 EEG, 2 EEGs, 3 grip pressures, writing pressure, elevation and azimuth angles, and 8 tracking points.

V. RESULTS

Table 3 shows the channels that satisfied Rule A for the three subjects. In this study, we focused on biological information. Therefore, data for Subject 3 was rejected because channel 43, the horizontal axis tracked by the camera, was not a biological channel.

Table 3. Channels that satisfied Rule A.

Subjects	Channels
Subject 1	25,28,30,32,33
Subject 2	3,22,30,41,43,46,49
Subject 3	43

Channels 25 and 30 on Subjects 1 and 3, and Channels 22 and 30 on Subject 2 were biological information channels. Channel 30 was the alpha wave, which was a common channel. Channel 25 was horizontal EOG, Channel 3 was the right neck, and Channel 22 was the left forearm. Fig. 6 shows the time-series variation of Channel 25 (EOG) for Subject 1, for a period from 200 to 1000 ms, where the stimulation was presented at 600 ms. Group 1 is non-stimulated trials, and Group 2 is stimulated trials. As shown in Fig. 6, the average amplitude of Group 2 was lower than that of Group 1, showing that the horizontal movement of the eyes of Subject 1 were reduced.

VI. CONCLUSION

The aims of this study were to investigate handwriting changes caused by auditory stimulation using an integrated measurement system and to examine the possibility of correcting changes in voluntary movements by using stimulation. Although the first aim was achieved, the second was not adequately achieved

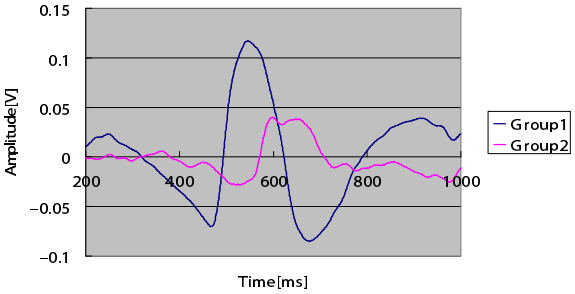

Fig. 6. Horizontal EOG of Groups 1 and 2 for Subject 1.

because none of the measured data channels satisfied Rule B, that is, the correction effect.

VII. FUTURE TASKS

In this study, we investigated the relations between character shapes and auditory stimulation in three subjects. However, we were not able to observe a correction effect induced by the stimulation. Our future work will involve experiments under other stimulation conditions and with more subjects.

ACKNOWLEDGMENT

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