Quantitative EEG Data and Comprehensive ADL (Activities of Daily Living) Evaluation of Stroke Survivors Residing in the Community

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Abstract
The purpose of this study was to investigate the hypothesis that EEG values match other comprehensive activities of daily living (ADL) evaluations between stroke survivors and normal controls. Various functions related to ADL were examined by means of ADL assessments (Measurement of Competence in the Elderly Living at Home, Barthel Index, Stroke Impairment Assessment Set, time needed to walk 10 metres) and biosocial synchronization (the questionnaire on biosocial rhythms of daily living). EEG was undertaken using a computer-assisted portable EEG recorder. The power spectra were computed using a fast Fourier transformation analysis (FFT). The absolute and relative powers (percent of the total EEG power) of 5 frequency bands (delta, theta, alpha 1, alpha 2 and beta) and the peak frequency were analyzed. In comparing stroke survivors and the independent elderly, the latter had higher scores than the former in assessments of various functions related to ADL. The absolute and relative power of the delta band were lower in normal controls, and the relative power of the alpha (2) band and the peak frequency were higher than those of stroke survivors. Among the correlations between EEG and ADL assessments, the absolute and relative power of the alpha (2) band correlated significantly with ADL assessments of stroke survivors with right hemiplegia. The peak frequency was significantly increased in cases with high ADL scores. In conclusion, significant correlations were identified between the quantitative EEG data of stroke survivors in the chronic stage, living in the community, and ADL-related functions. Computer-assisted portable EEG recording is a potentially useful screening tool for objectively evaluating the functional levels of stroke survivors in field work. J Physiol Anthropol 20 (1): 37-41, 2001 http://www.jstage.jst.go.jp/en/

Keywords: electroencephalogram, stroke survivor, ADL, synchronization

Introduction
It is important that elderly people strengthen the synchronization of biological rhythms in order to maintain a high level of activity of daily living and to assure a healthy and comfortable life. To develop a rehabilitation program related to synchronization of biological rhythms in the disabled elderly, the state of synchronization of biological rhythms must be evaluated. As one of the methods of evaluating synchronization of biological rhythms, the subjective evaluation method was developed by Motohashi et al. (1997). The electroencephalogram (EEG) is a well-established and reliable means of objectively monitoring brain function (Bricolo et al., 1978). In recent years, quantitative EEG analysis has been regarded as a useful objective measurement for evaluation of alertness and the level of diurnal activity (Stampi et al., 1995; Ota et al., 1993; Matousek et al., 1983). Elderly people who show good synchronization of the sleep-wake rhythm have a high level of activity in the daytime (Motohashi, 1999; Yuasa, 1998). Conversely, elderly patients with sleep disorders showed disrupted circadian rhythms for body temperature (Mishima, 1994). These findings may suggest the level of alertness and activity in the daytime to be related to the synchronization of biological rhythms. Thus, EEG may reflect the state of biological rhythms.

Aging has been suggested to be associated with the following EEG changes: slowing of the alpha frequency, decreased alpha and slow beta activity, increased theta and delta activity and focal temporal disturbances (Hartikainen, 1992; Mankovsky, 1971; Obrist et al., 1961). Matsuura et al. (1995) reported a relationship between the amount of alpha waves and psychometric evaluations such as the Benton visual retention and Kohs block-design tests. In a study of longitudinal changes in computerized EEG using Hasegawa’s dementia rating scale and the Bender-Gestalt test, Nakano et al. (1992) reported that the EEG slowing, increased theta waves, and decreased alpha frequency were more obvious in subjects with mental deterioration.
There have been only a few studies investigating the relationship between EEG abnormalities and ADL recovery in stroke patients (Kitamura et al., 1998). Giaquinto et al. (1994) reported that an EEG recorded in the weeks immediately after a stroke was not predictive of the patient's ADL recovery. In another study, EEG findings and their relationship to prognosis were studied in the acute to subacute stage, revealing severely abnormal EEG with diffuse slow waves to be associated with a poor prognosis which suggested that EEG findings reflect functional recovery in stroke patients (Kitamura et al., 1998). There have been few studies investigating the relationship between quantitative EEG in stroke survivors residing at home and comprehensive ADL assessment. The present study was designed to verify a) the comparison between stroke survivors and normal controls, b) the hypothesis that EEG values match other comparative measures between stroke survivors and normal controls residing at home.

Methods

Subjects

Thirty-one people, stroke survivors and independent elderly (controls) subjects whose ages ranged from 50 to 69 years, participated in the study. All subjects lived in the community, Natori City, located in the Tohoku Region of Japan. Stroke survivors consisted of 21 subjects living at home (13 males and 8 females). Twelve had left brain damage, 8 right brain damage and one bilateral brain damage. They were selected from a registered list of home health care services for the Natori City Health Center. Their mean age was 62.75 ± 6.2 (SD) years and the mean time since onset was 8.4 ± 6.2 (SD) years. They had experienced cerebral infarction or cerebral hemorrhage. We excluded those who had difficulty in understanding instructions or could not be interviewed. The independent elderly consisted of ten subjects who were healthy volunteers (3 males and 7 females). None had a history of neurological signs. Their mean age was 62.63 ± 5.13 (SD) years. There was no significant difference between the groups in terms of age. All subjects were informed of the purpose and protocol of the study prior to participation, and informed consent was obtained.

Instruments

Measurement of competence in the elderly living at home: This questionnaire measures three factors reflecting higher-level competence: instrumental self-maintenance, intellectual activity and social role. The competence score, ranging from 0 to 13, was calculated from the questionnaire. The higher the score, the higher the level of competence (Koyano et al., 1987).

Barthel Index: Ten functions were evaluated (feeding, moving from wheelchair to bed and return, personal toilet habits, getting on and off the toilet, bathing self, walking on a level surface, propelling a wheelchair, ascending and descending stairs, dressing and undressing, bowel continence, bladder control). Total scores range from 0 to 100 (total independence) in increments of 5. Functions are weighted according to their importance to independence (Mahoney et al., 1965).

Stroke Impairment Assessment Set (SIAS): This assessment set is used to evaluate various aspects of impairment in hemiplegics, including motor function, muscle tone, sensation, range of motion, pain, trunk control, visuospatial perception, aphasia and function on the unaffected side. The SIAS primarily employs single-task assessment of various functions and rates performance on scales of 0 to 5 or 0 to 3 (Chino et al., 1994).

Time needed to walk 10 m: This test is designed to evaluate the physical capacity of stroke survivors living in a community. The reliability and validity of the test were confirmed by Maeda et al. (2000). The test is considered to reflect both physical ADL and instrumental ADL. The time needed to walk 10 meters is measured using a stopwatch. The subject is instructed to walk as quickly as possible to the 11 m line, to ensure that his walking speed does not slow prior to reaching the 10 m line, but not to run.

Questionnaire to determine biosocial rhythms of daily living: This questionnaire measures the state of biosocial synchronization of the disabled elderly living in a community (Motohashi et al., 1997). The questionnaire is composed of eighteen items, and the items are as follows: bedtime, rising time, frequency of interruption of night sleep, quality of sleep, habit of daytime napping, regularity of meal time, frequency of urination, frequency of evacuation, frequency of going out, outdoor activity preference, difference in activity pattern between weekdays and holidays, feeling that time goes by fast communication with others, community participation, life satisfaction, subjective fatigue, and depressive mood. The questionnaire rates the subject's synchronization on a scale (0 to 2 or 0 to 4) and the total score ranges from 0 to 40. The total score of the 18 items is used as the score of the biosocial rhythms in this study.

EEG recording: The EEG recordings were conducted in the medical consultation room of the Natori City Health Center. The room was located in a quiet place and the curtain was closed. The room air temperature was controlled at 24 ± 1.0°C. The EEG recordings were performed from 10 a.m. to 12 noon and from 2 p.m. to 3 p.m. The EEG recordings were undertaken using a computer-assisted portable EEG recorder (BMI, Nouryoku Kaisatsu Kenkyujyo, Tokyo). BMI is a portable one-channel EEG recording apparatus that is connected to a personal computer. The EEG signals were digitized at a sampling rate of 128Hz and subjected to spectral analysis by a fast Fourier transformation (FFT).
EEGs showing artifacts were excluded from analysis. Power spectra were computed for 1-second epochs and integrated for the delta (1–3 Hz), theta (4–7 Hz), alpha 1 (8–10 Hz), alpha 2 (11–13 Hz), and beta (14–24 Hz) frequency bands. Each power was transformed into the magnitude values in microvolts. The reliability of measurements made with this apparatus was determined by comparing the BMI EEG frequency structure with that from a conventional clinical EEG recorder (Yuasa, 1998).

EEGs were recorded using electrodes placed on the left frontal scalp (Fp1) with the left ear as a reference. The time schedule used during EEG recording was as follows: (1) eyes closed for 30 seconds, (2) eyes open for 60 seconds, and (3) eyes closed for 60 seconds. The last 60 seconds of data were analyzed.

The absolute and relative powers of 5 frequency bands were obtained. The relative powers of each band were calculated by dividing each band power by the total power. The frequency with the most prominent power was detected as the peak frequency.

Statistical analysis
Statistical analyses were performed using the Mann-Whitney U-test to test the significance of differences between stroke survivors and the normal controls. The correlations were analyzed by Spearman’s correlation coefficient. The level of statistical significance was adopted as p<0.05.

Results
Significant differences were observed between stroke survivors and independent elderly in the competence score, the 10 meter walking time, the questionnaire on biosocial rhythms and bedtime (Table 1). In the EEG comparison between the two groups, absolute and relative powers of the delta bands of stroke survivors were significantly higher than those of normal controls and the relative power of the alpha (2) band was significantly lower in stroke survivors than in normal controls (Figs. 1, 2). The peak frequency was 7.95 ± 1.94 (mean ± SD) in stroke survivors and 9.50 ± 1.35 in normal controls, a statistically significant difference.

There were no significant differences in either the absolute or the relative power in any bands between subjects with right hemiplegia and those with left hemiplegia. The relationships between EEG and other assessments of the subjects with right hemiplegia are

### Table 1 The characteristics of the ADL related assessments in the stroke survivors and independent elderly

<table>
<thead>
<tr>
<th></th>
<th>Competence score</th>
<th>Barthel Index</th>
<th>SIAS</th>
<th>10 metre walking time</th>
<th>Rhythm score</th>
<th>Bedtime</th>
<th>Rising time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stroke survivors (n=21)</strong></td>
<td>5.6 ± 3.2**</td>
<td>84.0 ± 16.8</td>
<td>64.1 ± 14.0</td>
<td>20.2 ± 17.5**</td>
<td>23.6 ± 4.0**</td>
<td>20.8 ± 12**</td>
<td>7.0 ± 2.7</td>
</tr>
<tr>
<td><strong>Normal controls (n=10)</strong></td>
<td>12.7 ± 0.7</td>
<td>-</td>
<td>-</td>
<td>5.4 ± 1.4</td>
<td>29.7 ± 2.5</td>
<td>21.9 ± 0.6</td>
<td>6.0 ± 0.7</td>
</tr>
</tbody>
</table>

Values are means ± SD. Mann-Whitney U-test. *p<0.05, **p<0.01. SIAS: Stroke Impairment Assessment Set; The SIAS rates performance on scales of 0 to 3. The items evaluated include motor function, muscle tone, sensation, range of motion, pain, trunk control, visuospatial perception, aphasia and functions on the unaffected side.

**Fig. 1** Absolute powers in stroke survivors and the independent elderly. The difference in the delta band between the groups is statistically significant (Mann-Whitney U-test; *p<0.05, Bars represent the SEM).

**Fig. 2** Relative powers in stroke survivors and the independent elderly. The differences in the delta and alpha (2) bands are statistically significant (Mann-Whitney U-test; *p<0.05, Bars represent the SEM).
Table 2 Correlations between EEG and ADL related assessments in the stroke survivors with right hemiplegia (n=12)

<table>
<thead>
<tr>
<th></th>
<th>Delta absolute power</th>
<th>Delta relative power</th>
<th>Theta absolute power</th>
<th>Theta relative power</th>
<th>Alpha (1) absolute power</th>
<th>Alpha (1) relative power</th>
<th>Alpha (2) absolute power</th>
<th>Alpha (2) relative power</th>
<th>Beta absolute power</th>
<th>Beta relative power</th>
<th>Peak frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence score</td>
<td>-0.12</td>
<td>-0.55</td>
<td>-0.24</td>
<td>-0.47</td>
<td>0.14</td>
<td>0.03</td>
<td>0.78**</td>
<td>0.59*</td>
<td>0.63*</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Barthel Index</td>
<td>-0.19</td>
<td>-0.59**</td>
<td>-0.06</td>
<td>-0.39</td>
<td>0.24</td>
<td>0.22</td>
<td>0.74**</td>
<td>0.54</td>
<td>0.54</td>
<td>0.11</td>
<td>0.57</td>
</tr>
<tr>
<td>SIAS</td>
<td>-0.12</td>
<td>-0.34</td>
<td>-0.33</td>
<td>-0.58*</td>
<td>-0.12</td>
<td>-0.02</td>
<td>0.83**</td>
<td>0.80**</td>
<td>0.59*</td>
<td>0.28</td>
<td>0.64*</td>
</tr>
<tr>
<td>10 m walking time</td>
<td>0.34</td>
<td>0.47</td>
<td>0.13</td>
<td>0.33</td>
<td>-0.09</td>
<td>0.00</td>
<td>-0.62*</td>
<td>-0.70*</td>
<td>-0.50</td>
<td>-0.30</td>
<td>-0.71*</td>
</tr>
<tr>
<td>Rhythm score</td>
<td>0.38</td>
<td>0.41</td>
<td>0.44</td>
<td>-0.25</td>
<td>0.64*</td>
<td>0.45</td>
<td>0.36</td>
<td>-0.08</td>
<td>0.57</td>
<td>-0.08</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

Spearman’s correlation coefficient. *p<0.05, **p<0.01. SIAS: Stroke Impairment Assessment Set; The SIAS rates performance on scales of 0 to 3. The items evaluated include motor function, muscle tone, sensation, range of motion, pain, trunk control, visuospatial perception, aphasia and functions on the unaffected side.

shown in Table 2. In the subjects with right hemiplegia, there was a significant negative correlation between the relative power of the delta bands and the Barthel Index, and between the relative power of theta bands and SIAS. There was also a significant positive correlation between the absolute power of the alpha (1) band and the score on biosocial rhythms. In the alpha (2) band, significant positive correlations were seen between absolute power and the competence score, Barthel Index and SIAS, while there was a negative correlation with the 10 meter walking time. The relative power of the alpha (2) band was revealed to have significant positive correlations with the competence score and SIAS, and a negative correlation with the 10 metre walking time. The absolute power of the beta band correlated positively with both the competence score and SIAS. The peak frequency correlated positively with the competence score and SIAS, and negatively with the 10 metre walking time. The subjects with right hemiplegia tended to have more significant correlations than the subjects with left hemiplegia.

As for time-of-day effect on EEG values, there were no significant differences in powers between a.m. and p.m.

Discussion

In the present study, the stroke survivors were shown to have a lower prevalence of alpha (2) bands and beta bands, and a higher prevalence of delta bands and theta bands than control subjects. The stroke survivors had a lower peak frequency. Matsuura et al. (1995) reported that subjects with low psychological test results (Kohs block-design test and Benton visual retention test) showed significantly lower alpha activity and higher theta activity than subjects with high scores. Nakano et al. (1979) studied the difference in the peak frequency in the alpha band and reported that the dominance in the amount and amplitude of alpha waves was less prominent in an aged group than in a younger adult group. The present study, comparing stroke survivors and normal controls, supports the previous study indicating decreased alpha activity, increased theta activity and a lower peak frequency in subjects with low function.

The score of the questionnaire to determine the biosocial rhythms and ADL scores of subjects with right hemiplegia were significantly related to alpha bands. Williamson et al. (1990) reported that cognitive performance correlated positively with fast (beta) activity particularly in frontal leads, and that reduced beta activity might be an early indication of intellectual loss. Decreased alpha activity was also seen in their patients. It is interesting that both decreased alpha activity and decreased beta activity have been found in early cognitive decline. Our data from subjects with right hemiplegia appear to support such findings.

The correlation between the scores of the questionnaire to determine biosocial rhythms and ADL, and alpha activity, shown in this study, indicates that the state of synchronization of biological rhythms correlates closely with ADL in stroke survivors. The state of synchronization of biological rhythms and ADL scores are closely related to each other, but the score of the questionnaire on biosocial rhythms were correlated with alpha (1) band and ADL scores were correlated with alpha (2) band. This difference may be attributable to ADL scores (the competence score, Barthel Index, SIAS and 10 meter walking time) being performance scores, while the questionnaire on biosocial rhythms includes broad factors such as the sleep-wake rhythm.

As to the delta band, according to the previous study (Suzuki, 1972) the power spectra less than 3 Hz on the frontal area includes both artifacts caused by eye movements and original EEG of frontal area, and it is mostly impossible to separate artifacts from original EEG power on the spectra by FFT. Significant differences in the absolute and relative powers of the delta band between the two groups might reflect inclusion of artifacts.

Various ADL evaluations are used for stroke survivors, but such evaluations are sometimes subjective or apt to be partial (Tajima et al., 1998; Tanikawa, 1997; Law et al., 1989). In this study, EEG, one of the objective evaluation tools, especially of the alpha band, was shown to correlate with both ADL and biosocial rhythms.
The portable, computer-assisted EEG recorder used in this study is cost effective and the measurement time is short. The clinical and research applications of this portable EEG measurement device make it a valuable objective screening method for evaluating the functional level of stroke survivors. In this study, significant correlations between EEG findings and various ADL scores were seen in subjects in whom the affected hemisphere (left hemisphere) was reflected by right hemiplegia. It is recommended that EEG be used to monitor both the affected and the unaffected hemisphere in future studies.

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