EEG Changes during Mental Calculation, Reverse Recitation and Association Exercises in Patients with Dementia of the Alzheimer Type

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The cerebral functional impairment in dementia of the Alzheimer type (DAT) was quantitatively assessed using easily repeatable electroencephalographic analysis. Waveform recognition was employed to analyze the EEG (electroencephalogram) changes displayed before and after tasks of mental calculation, reverse recitation and mental association. Marked decrements in the incidence of theta and alpha waves together with decrements of the average amplitude of alpha waves were noted in normal elderly subjects after mental calculation and reverse recitation. In the patients with DAT, mental association tasks evoked pronounced decrements in the average amplitude of theta waves, the average frequency of alpha waves, and both the average frequency and average amplitude of beta waves. These results indicate that analysis of EEG activity responses to mental tasks provides an objective assessment of dementia. (Internal Medicine 32: 87-93, 1993)

Key words: senile dementia, mental exercise, alpha wave, beta wave

Introduction

Concomitant with the aging of the demographic profile in recent years, there is an increased incidence of senile dementia. Neurological research, therefore, is being conducted on various aspects of the effects of aging on mental and cognitive functions. Moreover, computerized tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) are now used to make objective evaluations in the differential diagnosis of the pathological assessment of dementia. These examination methods are not readily adaptable to routine clinical practice, and they lack definitive accuracy with respect to recognition of the initial phase of dementia. By contrast, EEGs provide a noninvasive means of investigation of cerebral function as well as a direct means of investigating physiological brain functions. Moreover, owing to progress in computer technology, EEGs can be used to make extremely detailed studies of cerebral function.

The appearance of abnormalities in the EEGs of patients with senile dementia has been noted in previous EEG studies (1-4). In addition, the degree of EEG abnormalities is reported to generally correlate well with the severity of dementia (5-7). In patients with only slight dementia however, a number of studies have been reported, but no definitive conclusions have been reached.

Here, EEGs were recorded both in the resting state and under mental loads in order to obtain an objective assessment of cerebral function impairment. The results show that EEG response is markedly diminished in the patients with dementia of the Alzheimer type, and there is a correlation with the impairment of cerebral function.

Patients and Methods

Subjects

The subjects of the study were seven normal elderly persons (NE group), aged 73.4 ± 11.0 (mean ± S.D.), and 10 patients with dementia of the Alzheimer type (DAT group), aged 78.6 ± 5.2. On the basis of pathological, physiological, and neurological findings, as well as clinical examinations (in particular, CT scans), the DAT group subjects were judged to be free of organic lesions to which dementia might have been attributed. The patients with severe dementia were excluded from the study. FAST (Functional Assessment Staging) was

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used to select only those patients in the early stage of dementia, that is, with stages between 2 and 4 (8). Most of the patients (7/10) were in stage 3. Moreover, to ascertain the severity of dementia, we gave the Hasegawa Dementia Scale (HDS), the Bender Gestalt Test (BGT), and Kohs' Block Design Test (BDT) as assays of neuropsychological function. The respective results for the NE versus the DAT group were 31.3 ± 1.1 (mean ± S.D.) versus 21.6 ± 4.7 points on the HDS; 42.0 ± 15.6 versus 117.0 ± 46.7 points on the BGT; and 64.1 ± 19.5 versus 19.8 ± 16.9 points on the BDT. These values confirm the existence of significant differences between the groups (P < 0.05).

**EEG measurement**

To avoid the effects of ocular movement and electromyograms, both of which present problems in connection with EEG observations, EEG data were obtained in a resting, supine position with the eyes closed. EEGs were recorded from 12 sites: Frontal (F) 3; F4; Central (C) 3; C4; Parietal (P) 3; P4; Occipital (O) 1; O2; F7; F8; Temporal (T) 5; and T6. A common electrode connecting both ear lobes was used as the reference electrode. Recordings were made with a 0.3 s time constant and a 120 Hz high band cut-off filter. At the same time as the EEG recordings, the instant of presentation of the mental exercise by the experimenter and completion of the replay by the subject were recorded as pulse signals by means of a push button. The results showed that the interval required for attempting the exercise (estimated from the time between the presentation of the exercise and the completion of the replay) was approximately 5–10 seconds. Accordingly, the resting time was set at 8 seconds on the basis of the mean exercise attempt interval.

**EEG analysis**

Twelve-channel EEGs educed with an electroencephalograph (Nihon Koden, Model EEG-4217) were recorded with a data recorder (SONY, Model A614). A minicomputer (NDG Co., Model GW4000), A (analog)/D (digital) then was used to make conversions at 1 ms intervals, the output being analyzed by the waveform recognition method. The principal of this method relied upon changes in slope and constriction of the triangular-type configuration in determining the peaks of original waves. Using the center-of-gravity search system, original waves were distinguished between the single and superimposed waves. The detailed description of these processing stages were reported previously (9, 10) (Fig. 1). Then, the amplitude and duration of all waves were determined as follows: the amplitude of each wave was measured by the height between a peak and the cross point, in which the perpendicular line drawn from a peak to the baseline meets with the line joining two trough points. The duration is determined from the time course between the two successive trough points.

Of the various quantitative EEG values, 3 dimensions of 4 major frequency bands were statistically analyzed. The band comprised delta waves (0.5–3 Hz, ≥30 μV), theta waves (3–8 Hz, ≥15 μV), alpha waves (8–13 Hz, ≥5 μV), and beta waves (13–30 Hz, ≥5 μV). The dimensions consisted of 1) the incidence (% time), the ratio of the total wave time to required interval of respective frequency bands; 2) the average frequency, the mean value of the frequencies of all waves in a required interval of respective frequency bands; 3) the average amplitude, the mean value of the amplitudes of all waves in a required interval of respective frequency bands. From the results obtained, the mean values of the dimensions were calculated for each band for each subject for the resting period interval prior to attempting the mental exercise (approximately 2 minutes per individual), as well as for the interval during which the exercise was attempted (approximately 3 minutes per individual). The percent of change in each of these parameters after the exercise had been attempted was determined relative to the mean values recorded for the respective subjects during the resting periods and used as reference values. Lastly, the Welch test was used to compare the values for each of the 12 EEG leads in the group of 7 NE subjects with the corresponding values for
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Mental exercises

The mental exercises used were three types of tasks that could be solved within a short time: mental calculation, reverse recitation, and association problems. The calculation problems consisted of adding or multiplying two-digit and one-digit numbers (e.g., 43 + 7 or 12 × 6). The objects for reverse recitation were three-digit numbers (e.g., 732). The association problems consisted of recollecting three names related to a single topic (e.g., the names of three flowers). Because the time allowed for solving a single problem was short, the problems presented were 10–15 per trial.

Results

(A) Characteristics of the various frequency bands obtained during resting intervals for the NE and DAT groups (Fig. 2).

I) Incidence (% time)

Regarding the theta waves, the DAT group showed generally higher incidences than the NE group; a difference of approximately 20% was recognized for all the leads. For alpha waves, the DAT group showed generally lower incidences; a significant difference of approximately 30% was recognized for all the leads (P < 0.05). For beta waves, the DAT group showed generally lower incidences, with a significant difference of approximately 30% recognized for all the leads (P < 0.05).

II) Average frequency

No significant difference between the two groups was found for the frequency of theta and alpha waves. Regarding beta waves, the DAT group showed generally lower frequencies than the NE group; a significant difference of approximately 4 Hz was recognized for all the leads (P < 0.05).

III) Average amplitude

No significant difference between the two groups was found with respect to the amplitude of theta waves. For alpha and beta waves, the DAT group generally showed lower amplitudes than the NE group.

(B) Comparison of proportionate changes in the NE and DAT groups after attempting mental exercises

I) Mental calculation exercises (Fig. 3)

The incidence of theta waves in both groups was decreased; significant differences between the two groups exceeding 30% were noted in the F3, P3, P4, F7, F8, F5, and T5 leads (P < 0.05).

The incidence of alpha waves overall decreased by 20.9% to 35.4% for the NE group; whereas, for the DAT group it increased by 2.9% to 13.8% in the P3, P4, O1, O2, and T5 leads. The average frequency overall increased by 0.5% to 3.7% for the NE group. For the DAT group, however, it decreased by 1.6% to 17.5%. The average amplitude decreased by 25.0% to 33.2% for the NE group and by 11.2% to 19.0% for the DAT group.

The incidence of beta waves slightly increased in the O1, O2, F7, F8, T5 and T6 leads for the NE group. The average frequency of waves also was slightly increased for the NE group; for the DAT group, however, it decreased by 12.4% to 28.8%. Significant differences between the two groups with respect to average frequency were found for all but the F3 leads (P < 0.05).

II) Reverse recitation exercises (Fig. 4)

The incidence of theta waves in both groups was decreased, with a particularly pronounced decrement occurring in the NE group.

The incidence of alpha waves overall decreased for the NE group; whereas, for the DAT group, it increased in some leads. Except for the frontal region, there were significant differences between the two groups (P < 0.05). The average frequency increased for the NE group; for the DAT group, however, it decreased in the central and parietal regions (P < 0.05). The average amplitude decreased by 28.0% to 40.1% for the NE group and by 2.3% to 12.8% for the DAT group. These values represented significant overall differences for the groups (P < 0.05).

The incidence of beta waves was slightly increased in the P3, P4, O1, O2, F7, F8, T5 and T6 leads for the NE group. As for the average frequency of beta waves, almost no changes were found for the NE group; for the DAT group, however, the average frequency was generally decreased by 4.6% to 19.5%.

III) Mental association (Fig. 5)

The average amplitude of theta waves in both groups overall decreased; pronounced differences were recognized for both groups in all leads except those in the occipital and temporal regions.

The average frequency of alpha waves increased by 1.9% to 3.9% for the NE group; whereas, for the DAT group it decreased by 5.7% to 15.5%. These values represented significant overall differences for the groups (P < 0.05).

The incidence of beta waves increased by 4.3% to 13.8% for the NE group; for the DAT group, however, it decreased by 4.2% to 35.2%. Average frequency was slightly increased for the NE group; for the DAT group, however, it was decreased 25.9% to 34.1% (P < 0.05). The average amplitude decreased by 9.1% to 12.8% for the NE group and by 28.6% to 40.1% for the DAT group. These values represented significant overall differences for the groups (P < 0.05).

Discussion

EEG analysis has been widely used for the diagnosis of dementia, with varied results reported. We have recorded and compared EEG changes concomitant
Fig. 2. Mean values at rest for the NE and DAT groups. Mean value and S.E. are shown on each of the 12 bars for the rest states. Vertical T bars show the standard error. Open bars NE group; dotted bars DAT group. * P < 0.05.
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The results showed that, in terms of the mean values for resting EEGs, in the DAT group the overall incidence of theta waves increased but the incidence and average amplitudes of alpha waves showed overall decrements, in agreement with previously reported results (1–4). In the initial stage of dementia, however, there were no clear differences from the values for normal elderly persons. Consequently, the significance of resting EEGs with respect to making early diagnoses is limited. Studies that incorporate the EEGs evoked by mental tasks therefore, are necessary for obtaining a valid assessment.

The results of our comparison of the proportionate changes associated with attempts to perform mental tasks showed pronounced decrements in the incidence of theta waves in the NE group, as well as in the incidence and average amplitude of alpha waves. This was in response to the imposition of mental calculation and reverse repetition exercises. In the DAT group, the average amplitude of the theta waves, and the average frequency of the alpha waves, as well as the incidence, average frequency, and average amplitude of the beta waves, showed pronounced decrements in response to mental association exercises. In particular, responsiveness to reverse recitation exercises showed particularly pronounced degradation. This is attributed to the connection between reverse recitation tasks and short-term memory functions that are prone to deterioration during the initial phase of dementia. This phenomenon also suggests there are effects from the deterioration of neural functions in the hippocampi and frontal lobes, which are considered to be related to senile amnesia.

Dementia of the Alzheimer type has been linked to overall cerebral atrophy and dilatation of the lateral ventricles seen in CT and MRI images (11, 12), and to oxygen consumption in cerebral blood flow, and to oxygen consumption in the temporal and parietal lobes in PET and SPECT findings (13–16). The appearance of slow wave components in dementia patients at rest is reported to be associated with cerebral circulatory and metabolic defects (17, 18). The increased incidence of theta waves that we found also is regarded to reflect deterioration of cerebral circulatory and metabolic functions.

Research on reactions to photic or acoustic stimuli and hyperventilatory activation, as well as on the attenuation of alpha waves when opening the eyes, has been conducted for the purpose of making effective diagnoses of senile dementia (7, 19–21). Alpha waves originate both in the thalamocortical system and in the cerebral cortex; whereas, beta waves principally originate in the cerebral cortex (22). As judged from the regions of origin of the respective waves, the decrements seen in the attenuation of alpha waves, in the fast wave components of the alpha waves, and in the incidence of

Fig. 3. Rates of change during mental calculation. Values are shown for the proportionate changes of mental activity based on the resting state. Vertical T bars show the standard error. Open bars NE group; dotted bars DAT group. * P < 0.05.
beta waves, all of which were concomitant with subjects of the DAT group when attempting to do mental exercises, indicate impairment of the cortical and subcortical regions in the DAT group in contrast to the cerebral activation found for the NE group.

Almost all the reported studies of resting EEGs have
been concerned with the power spectrum computed by the FFT (Fast Fourier Transformation). Using waveform recognition methods, we were able to detect minute EEG changes in subjects at rest and during the performance of assigned mental tasks. The EEG changes noted in our study are regarded to reflect direct cerebral functional impairment. In conjunction with CT and PET findings, analyses of EEG changes induced by attempts to perform mental tasks promise to provide useful incidences for objective assessment in relation to such aspects of senile dementia as its diagnosis, assessment of progression, and the evaluation of the efficacy of medication.

References