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HEMISPHERIC FUNCTION OF JAPANESE ABACUS MASTERS: AN EXAMINATION BY ELECTROENCEPHALOGRAPH*

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To examine the hypothesis that the right hemisphere engages more strongly than the left in mental calculation in abacus masters whereas the left hemisphere engages more strongly in ordinary people, EEG activities during mental calculation task and news listening task were measured. EEG power variations from resting state were analysed as a function of the frequency bands and brain regions. Parametric analyses did not necessarily support to the hypothesis while nonparametric results supported the hypothesis.

It is well known that so-called experts show unbelievably superior performance. For example a chess master recalls more than hundreds of movements correctly. This is also the case in Go-masters and Shogi (Japanese chess) masters. They can memorize and recall all steps-movement of piece sequences. Not only they can recall the sequences of pieces-movement after the game but also they can recall all pieces-movement of hundreds of previous other famous games.

It is also well known that Japanese abacus masters can solve huge amount of calculation problems in unbelievable speed and their calculations are always accurate. For example, abacus masters need only several hundred ms (just to write down the answers) to solve problems. Their required time for complete the calculation is much shorter than calculation using a computer. The abacus experts are again superior in digit memory function. They can correctly recall 12 to 14 digits sequences either in backwardly or forwardly (Hatano & Osawa, 1983).

Why can they show such superior performances? In the case of the chess masters, it is revealed that they can employ a special cognitive strategy. Chase and Simon (1973) proposed that the chess masters use a special strategy of hierarchically organized long chanks.

What type of special strategy do the abacus experts employ to call for fast and accurate calculation? In the present experiment, we are going to focus some light on this question.

In the previous studies, it has been suggested by the behavioral measures that abacus experts can employ an imagery strategy or their right hemisphere in mental calculation while ordinary people use their left hemisphere. For example, Hatta and

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Ikeda (1988) conducted a series of experiment with time-sharing task. Their results showed that in mental calculation task, abacus experts showed greater interference effects of left hand tapping, whereas control subjects showed greater interference effects on right hand tapping. Based upon the rationale of a time-sharing task, these findings suggested that the right hemisphere engaged in mental calculation for the abacus experts whereas the left hemisphere contributes to mental calculation in ordinary people having no experience of abacus training. Further, Hatta, Hirose, Ikeda and Fukuhara (1989) conducted digit memory task experiments using abacus experts and ordinary people. Pictures of abacus figure, pictures of digit sequence, and human faces were presented to the subjects during the digit memory retention interval. The abacus experts experienced greater interference from the presentation of the abacus figures than digits and human faces, on the other hand control subjects were interfered more by the presentation of digits than abacus figures and human faces. These results suggested that abacus experts employ an imagery strategy, i.e., mental abacus which is analogous to the actual one.

The purpose of this experiment was to examine the suggestion by the previous behavioral studies using electrophysiological measures. Therefore, the hypothesis to be examined was as follows; the right hemisphere of the abacus experts is engaged more than the left in mental calculation, while the left hemisphere of the control subjects is engaged more in the mental calculation.

To examine this hypothesis, EEG activities during the mental calculation of the abacus masters and control subjects were measured.

METHOD

Subjects: Eleven abacus masters (3 males and 8 females) were the subjects of the experimental group. Their skills were ranked from 5 to 10-dan (mean 7.6-dan) and their mean age was 21.7 years old. The control group consisted of ten university students who had negligible experience of abacus learning.

Apparatus for recording and analysis of EEG: EEGs were recorded with 16 Ag-Agcl electrode affixed to the subjects scalp at Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T5, T6, Fz, and Pz and referenced to the linked ear electrodes.

The subjects were grounded with an electrode placed on the flat part of the cheek. The San'ei IA58 Electroencephalograph set to a time constant of 0.3 s and an upper half-amplitude cut off of 30 z, were used. The vertical and horizontal electro-oculograms (EOG) were recorded to check an artifact produced by both eyes movement and blinks.

EEGs were recorded both on the paper and magnetic tape. After the experiment, tape recorded EEGs were analyzed by the digital computer, NEC San'ei Co. Ltd. Model 7T1T, in order to get the topographycal mapping of scalp EEG. The original processing program was made with Signal BASIC No. 5.

In this system, topographycal mapping was made in the following manner. Initially, 16 channel EEGs were sampled for 10.28 sec with a sampling clock of 10 ms. In this experiment, the sampling period was started just after the onset of auditory stimuli. The A/D converted data without any artifacts was divided into 10 periods, each of which has sequential 128 points. The latter 28 points on each epoch were overlapped on the next period. For each epoch, data were subtracted by the averaged value and processed by the cosine taper for each channel. Then FFT analysis was done on these 10 periods epochs separately. The mean power spectrum was calculated by summing across these 10 power spectrums and divided by 10 for each channel. In this manner, 16 channel power spectrums were given on one trial.

The mean power in each frequency band, delta (−2.8 Hz), theta (3.0–7.8 Hz), alpha-1 (8.0–9.8 Hz), alpha-2 (10.0–12.8 Hz), beta-1 (13.0–19.8 Hz), and beta-2 (20– Hz) were calculated for each channel. The topogram for each frequency band was drawn by the linear interpolation methods.

In this report, the mean power for each condition for each subject was given by averaging across five trials on the same condition. The group mean EEG topogram for each frequency band was given by averaging the mean powers across subjects.

Procedure: Each subject wearing EEG electrodes sat facing a screen and was given auditory mental calculation task and news listening task. In news listening task, subject was asked to listen carefully to a news article read with moderate speed by a male voice and to answer the experimenter's question (recall of a keyword) which was given at the end of each trial. The duration of each news article was approximately 15 s. In mental calculation task, each subject was requested to start mental calculation when he/she heard problems given auditorily and to give the answer after each trial. To randomize presentation order, half subjects were given news listening task first and mental calculation task second, and the other half subjects were given two tasks in the reversed order.

Results and Discussion

Before introducing the results, it must be better to explain briefly what about the Japanese abacus is like.

In Japan (and some area in main land China or Taiwan), the abacus (SOROBAN in Japanese) has been employed as an instrument for calculation and it has been regarded as one of the three basic intellectual abilities; these are reading, writing, and calculation with abacus. Even today, an importance is attached to skill at abacus by almost all Japanese, and institutional efforts at abacus training to children are organized both in school and in extracurricular programs. Japanese children are given the first introduction in the 3rd or 4th grades of primary school as an official curriculum.

Originally the abacus was adopted from China about 400 years ago and consisted of a wooden-framed instrument made up of 23 columns of beads.

The abacus is used to represent numbers in the decimal system. Each column of movable beads makes a reed showing a place value of "ones", "tens", "hundreds" and so on from the right to the left. According to the operator's convenience, once arbitrarily selected column of beads is defined as the "ones", all other columns are valued relative to it. Each column of beads is devided by a bar into two parts; upper part containing one bead and a lower part containing four beads. The value of the bead on the upper section is equal to five times the values of each bead on the lower section. When the upper bead stays off the dividing bar, it shows 0, but if stays on the bar, it shows 5. Whereas each of the lower beads represents 1 if it stays closer to the bar, and 0 further from the bar.

Rating of abacus skill begins at 10th-kyu and rises up to 1st-kyu, and then 1st-dan to 10th-dan. Generally, 1st-dan to 6th-dan can be regarded as experts, and over 7th-dan up to 10th-dan as masters.

Fig. 1 (a) shows topographical representation of the mean powers of EEG in the mental calculation condition of the abacus masters. Fig. 1 (b) shows those in the news listening condition of the abacus masters.

Fig. 1 (c) and Fig. 1 (d) show topographical representation of the mean EEG powers of the mental calculation task and the news listening task in the control

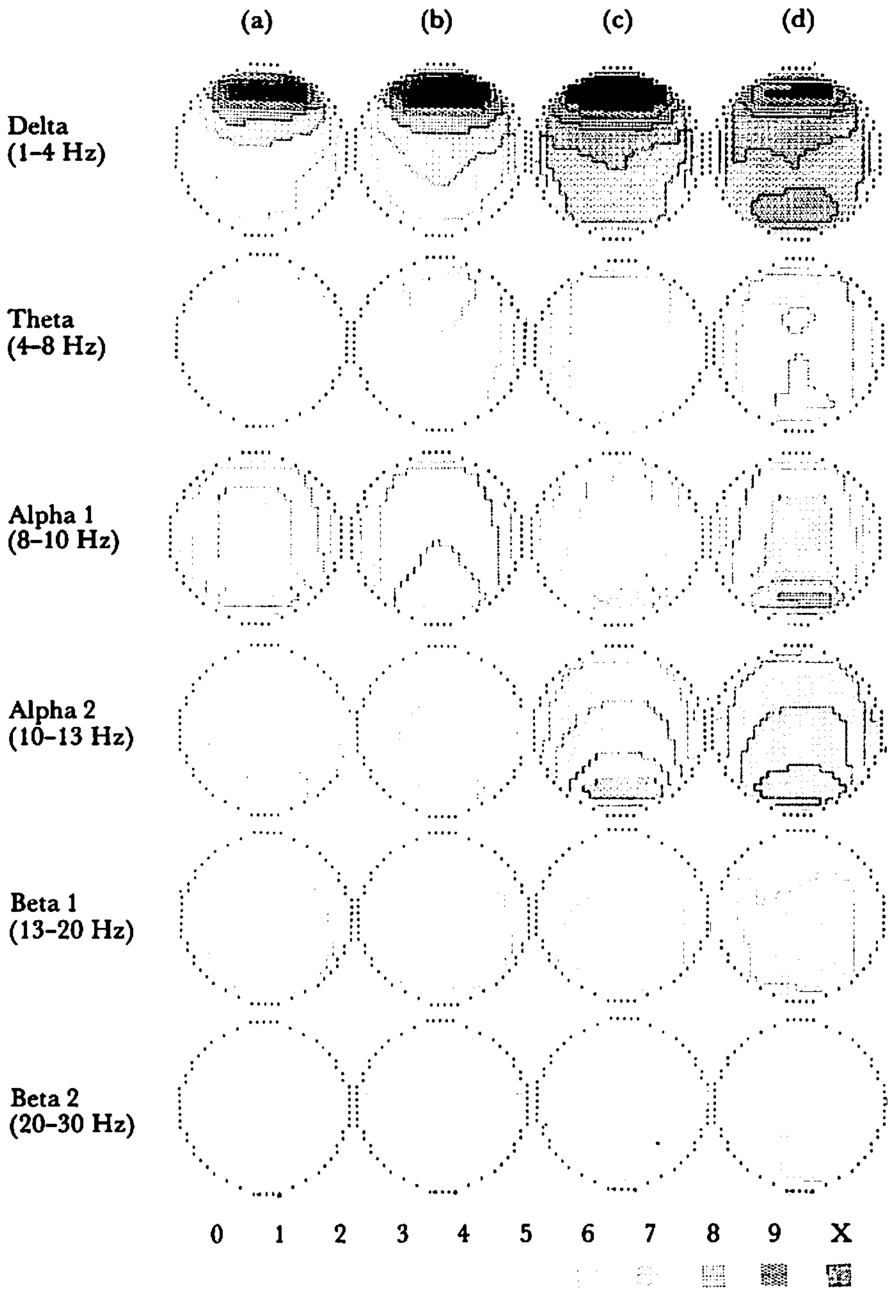

Fig. 1. EEG power topogram in the mental calculation condition of abacus masters (a), in the news listening condition of abacus masters (b), in the mental calculation condition of control subjects (c), and in the news listening condition of control subjects (d).

Table 1. Mean Power Variation Scores as a Function of Group of Subjects, Task Condition, EEG Frequency, and Brain Regions

Hemisphere			News task		Calculation task	
			left	right	left	right
Theta	Exp Gr.	M	8.47	8.62	7.35	5.51
		SD	7.72	8.22	6.13	5.82
Central	Cont Gr.	M	4.47	5.61	7.60	7.20
		SD	7.84	8.80	10.57	10.09
Theta	Exp Gr.	M	10.13	10.00	7.86	7.14
		SD	9.28	7.01	9.26	6.68
Parietal	Cont Gr.	M	4.52	7.25	4.75	8.65
		SD	7.93	9.72	7.72	8.27
Theta	Exp Gr.	M	10.42	10.23	6.69	5.37
		SD	10.32	6.98	10.03	4.79
Occipital	Cont Gr.	M	5.82	7.98	7.12	9.09
		SD	11.32	9.94	12.08	11.24
Alpha 1	Exp Gr.	M	4.51	3.57	0.06	−1.35
		SD	6.63	9.06	4.98	8.84
Central	Cont Gr.	M	16.00	14.97	17.75	15.65
		SD	11.82	10.28	19.43	20.32
Alpha 1	Exp Gr.	M	7.43	6.25	5.03	4.21
		SD	9.51	12.69	8.61	9.84
Parietal	Cont Gr.	M	16.93	17.32	17.19	13.41
		SD	14.08	14.15	21.85	23.62
Alpha 1	Exp Gr.	M	10.02	7.85	6.83	5.62
		SD	13.06	12.32	9.49	10.22
Occipital	Cont Gr.	M	11.57	13.27	15.44	17.31
		SD	18.25	17.13	23.45	22.58
Alpha 2	Exp Gr.	M	2.80	5.29	4.93	3.51
		SD	11.53	9.54	7.82	10.11
Central	Cont gr.	M	9.48	2.90	12.72	9.21
		SD	13.87	16.95	13.68	18.00
Alpha 2	Exp Gr.	M	3.64	4.29	7.92	8.03
		SD	7.72	7.14	7.35	9.76
Parietal	Cont gr.	M	10.06	4.47	14.20	8.44
		SD	16.82	19.11	14.32	17.94
Alpha 2	Exp Gr.	M	2.92	1.20	10.20	11.20
		SD	10.58	12.19	10.59	11.16
Occipital	Cont Gr.	M	10.15	7.21	10.79	8.25
		SD	20.46	21.95	16.16	17.76

subjects.

At the first glance, Fig. 1 (b) shows that the abacus masters showed clearer lateral asymmetry and more prominent theta band frequency emerging at the frontal region. It is known that the FM theta is seldom observed in the ordinary people and reflects deeper concentration (Yamazaki, Mitsuhashi & Yamada, 1988).

For the statistical analyses, the score of power variation was calculated individually.

This refers: Power variation score=((powers in the resting period)−(powers in the cognitive task period))/((powers in the resting period)−(powers in the cognitive task period))$\times$100

Table 1 shows mean power variation scores as a function of task condition, EEG frequency bands and brain regions.

ANOVAs (one between (group) and two within (task and left/right hemisphere) mixed type) conducted for each frequency band and brain region. The results statistically significant were as follows;

1) The theta band of the parietal region: Group difference was shown in the powers. That is, the abacus masters and experts showed no lateral difference but the control subjects showed bigger powers in their right brain ($F(1,19)=4.83$, $p<0.041$). These reflect that the brain activity of the abacus masters was higher than that of the control subjects and the left brain showed higher activity than the right in the control subjects.

2) The theta band of the occipital region: The abacus masters showed larger power variation in the news listening task condition, while the control subjects showed larger power variation in the mental calculation condition ($F(1,19)=5.20$, $p<0.034$).

3) The alpha 1 band of the parietal region: Powers variation of the control subjects was larger than that of the abacus masters ($F(1,19)=4.19$, $p<0.05$).

4) The alpha 2 band of the parietal region: The control subjects showed no lateral difference while the abacus masters showed larger power variation in their left brain ($F(1,19)=4.53$, $p<0.047$). This means that the activity of the right brain was larger than the left one.

Once Tojoh (1978) measured EEG alpha power of ordinary university stundents during mental calculation and several imagery tasks. He demonstrated different hemisphere (parietal lobe) activities as a function of task. That is, the attenuation of alpha activity in the right hemisphere during mental arithmetics was larger than in the left hemisphere, while the reverse was the case during the visual imagination of a scenery. Further, he found some difference in the analysis of nonparametric analyses that four among eight subjects showed larger alpha powers in the right hemisphere in mental calculation task and one among eight showed larger alpha powers in the left hemisphere. These findings suggest larger left hemisphere engagement in mental calculation and larger engagement of the right hemisphere in scenery imagination in ordinary young adults. The present results of the control group subjects did confirm his findings. The discrepancy is probably owing to large individual differences in EEG activities and task differences.

Table 2. Number of Subjects Who Showed Lateral Difference in Their Power Variation

		News: Right H. > Left H. Calculation: Left H. > Right H	News: Left H. > Right H. Calculation: Right H. > Left H.
Parietal	Exp.	3	1
alpha 1	Cont.	1	0
	Exp.	1	3
alpha 2	Cont.	2	0
Central	Exp.	2	0
alpha 1	Cont.	2	1
	Exp.	3	1
alpha 2	Cont.	0	0
Occipital	Exp.	1	1
alpha 1	Cont.	2	1
	Exp.	6	0
alpha 2	Cont.	0	0

Table 2 shows the frequency of the subjects who showed lateral difference in their power variation. The most prominent point is where six abacus experts showed larger right brain variation in the news listening and the larger left brain variation in the left hemisphere. This reflects the right hemisphere engagement in calculation and the left hemisphere engagement in the news listening tasks. No control subjects showed such pattern of power variation.

The results of ANOVAs do not necessarily support the hypothesis clearly that in the case of abacus masters, a stronger right hemisphere engagement occurs in mental calculation and left hemisphere engagement in the news listening. However, the nonparametric analyses partly support the hypothesis.

As shown the previous study, the individual variance of the EEG activity is somehow large, we need further experiments to verify the hypothesis that the abacus masters possess different brain function.

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