

Comparison Between Event Related Potentials Obtained by Syllable Recall Tasks and by Associative Recall Tasks

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Abstract. The final goal of this research is to establish some useful verbal communication systems between computers and persons, or between handicapped persons and normal persons. For a substantial progress toward the research goal, we investigate Event Related Potentials (ERP's for short) caused by Electroencephalograms (EEG's for short). By observing ERP's, we estimate recalled words, phrases, or sentences that may contain some homonyms or related words. In particular, we pay attention to the difference between ERP's caused by recalling a single syllable individually without other syllables and ERP's caused by recalling a syllable together with a word containing the syllable. From our observation of this difference, we believe that it may be useful to discuss the possibility of estimating a recalled word by combining ERPs caused by syllables.

Keywords: EEG, ERP, syllable recall, association.

1 Introduction

It would be nice if the progress of computer technology and brain science makes possible or easier for disabled or paralyzed individuals to communicate with their external surroundings. The research problem discussed in this paper has been motivated by this kind of desires and needs. Cognition events of a human being are controlled by electric signals sent from his/her brains. From this fact we intend to design a brain-computer interface using electroencephalograms (EEGs). As meaningful signals from the brain, event related potentials (ERPs) are measured from EEGs¹.

We show that ERPs are clearly related to cognitive events such as visual stimulation, auditory stimulation, and others. ERPs have been much studied in various areas, e.g., medical science, ergonomics, psychology, and others. The purpose of this paper is to confirm that the following assumption is acceptable or to give evidence for

the assumption. "We can guess correctly a word from ERP's obtained by recalling the syllables that are components of the word."

2 Methodology

2.1 Experiments

We repeat the following experiment four times:

- 1) The subjects: Two persons whose ages are 21 years old. We use "sub 1" and "sub 2" to identify them.
- 2) The place of the experiments: The laboratory of the first author at Hakuoh University.
- 3) Recalled words: We use five words. These are an apple, an orange, a strawberry, a banana, and a melon. Each of these words consists of three syllables in Japanese as follows: apple: ri-n-go, orange: mi-ka-n, strawberry: i-chi-go, banana: ba-na-na, melon: me-ro-n
- 4) Recalled Syllables: The fifty syllables used in Japanese are divided into ten groups as follows:
a-group {a, i, u, e, o}, ka-group {ka, ki, ku, ke,ko }, sa-group { sa, si, su, se, so}, ta-group { ta, ti, tu, te, to}, na-group {na,ni,nu ne,no}, ha-group {ha, hi, hu, he, ho}, ma-group { ma, mi, mu, me, mo}, ya-group {ya, yi, yu, ye, yo}, ra-group {ra, ri, ru, re, ro}, wa-group { wa, wi, wu, we, wo}
- 5) Stimuli: We use five sets of combinations of producing districts and products (fruit). Each of the combinations starts from two Chinese characters. One is a producing district followed by the other, a fruit name. When we use each combination as a stimulus to a subject, one syllable among the last three syllables is replaced by a pause. The experiments are to measure how the subject properly recalls the paused syllable from the producing district and other two syllables of the fruit name. These patterns are depicted in Fig.1, where the squares indicate positions of displayed syllables, and dark squares indicate positions of paused ones (i.e., not displayed ones).



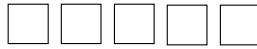
Fig. 1. The formats of stimuli

We call five sequences of producing districts followed by fruit names containing pauses "a term". A term is repeated twice for each instance. Such a set of two terms are called "a set" or "a set" of experiments. Five sets are repeated. After another kind of experiments, the subjects take again five sets. The interval between two consecutive sets of the experiments is 1 minute for the rest of the subjects.

- 6) Syllable stimuli: We use similar formats for syllable stimuli to the formats explained in 5) above. The formats for syllable stimuli are shown in Fig.2, where

two problems are given. The first one consists of five syllables and the second one is a pause followed by 4 syllables. Other types of problems are also possible but we omit them here.

1. A phrase from a poem consisting of five syllables



2. A phrase from a poem but the first syllable is paused

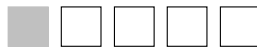


Fig. 2. Examples of formats for syllable stimuli

- 7) Display of stimuli: a sequence of stimuli is displayed on a 19 inches-CRT (cathode-ray tube) in front of the subjects. The size of the stimuli on the CRT is small enough for the subjects to see them without moving their eyes.
- 8) Tasks for each subject: A subject recalls five fruit names given in 3) above. When the first pattern in Fig.1 is displayed, the subject tries to determine which fruit he/she recalls. When the second pattern is displayed, the subject recalls the first syllables, when the third one is displayed, the subject recalls the second syllable, and so on. In this experiment, “recall” means to pronounce words in their mind without sound and moving their tongues.
- 9) A period for displaying a stimulus: Each stimulus in Fig.1 is displayed for 1 second. An interval between two consecutive stimuli is at random within the range from 800ms to 1200ms.
- 10) Duration of an experiment: About 1.3 minutes are spent for a set of experiments, and 1 minutes are used for a short rest in the interval between two consecutive sets of experiments. Consequently the total experimental time for 5 sets of experiments is 6.5 minutes excluding intervals between sets.
- 11) EEGs: Single polar eight channels of “International 10-20 methods” are used for measuring EEG’s. The measurement positions are Fp_1 , Fp_2 , C_3 , C_4 , O_3 , O_4 , C_z , and P_z . The base is A_1 connected to A_2 .
- 12) The sampling frequency for A/D: 1 kHz.

2.2 Analysis

- 1) Recorded EEGs ($EEG_i(t)$, $i=1,2,\dots,20$, $t=1,2,\dots, 1000$) are divided into five groups and four parts. Each EEG corresponds to a syllable or a problem .
- 2) The EEG’s in each group are filtered by an adaptive filter made by the first author.
- 3) We normalize the filtered data ($EEG_i(t)$, $i=1,2,\dots,n$, $t=1,2,\dots, 1000$) by the average of them, $m(EEG_i)$ and the standard deviation $sd(EEG_i)$.

$$NEEG_i(t) = \frac{EEG_i(t) - m(EEG_i)}{sd(EEG_i)} \tag{1}$$

- 4) We average the normalized twenty EEG's to obtain an ERP evoked by recalling a character and use a symbol $ERP_{kj}(t)$ to indicate the obtained ERP. "k" indicates a fruit name, and "j" indicates a pattern (format) of stimuli in Fig.1. ($k=1,2,3,4,5, j=1,2,3,4, t=1,2,\dots,1000$)

$$EEG_{kj}(t) = \frac{1}{20} \sum_{i=1}^{20} NEEG_{kji}(t) \tag{2}$$

- 5) Since we repeated the experiments four times, we take the average of the four sampling data for $ERP_{kj}(t)$ to obtain a typical value of ERP for each syllable. We use $SERP_{kj}(t)$ as the average.

$$SERP_{kj}(t) = \frac{1}{80} \sum_{i=1}^{80} NEEG_{kji}(t) = \frac{1}{4} \sum_{i=1}^4 ERP_{kji}(t) \tag{3}$$

3 Result

3.1 Recorded Data and Filtered Data

An example of measured data $eeg_i(t)$ is shown in Fig.3. The subject in Fig. 3 is "sub 1", and she recalls "a" in a syllable recalling task during the first set. The horizontal axis and the vertical axis of the graph are time in millisecond (ms) after a stimulus is displayed, and the amplitude of EEG's, respectively. The waves in the graph show the EEG's measured at C₄, C₃, Fp₂, and Fp₁. Various types of noises such as 50Hz alternating current, eye blinking, and electromyogram are also included in the EEG's.

The data after being filtered and normalized are shown in Fig.4. Noises such as alternating current, whose frequencies are higher than the fundamental frequency of EEGs, are attenuated.

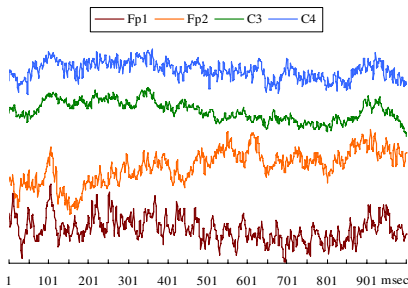


Fig. 3. An example of recorded data $eeg_i(t)$

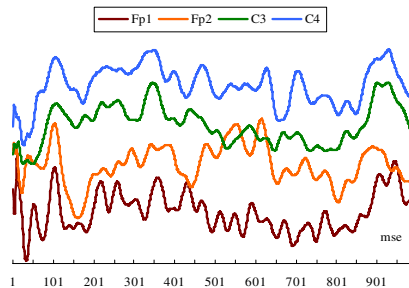


Fig. 4. The filtered and normalized data $NEEG_i(t)$

(sub-1, C3, The first "a" in the 1st set at the first experiment)

3.2 An ERP Obtained by an Associative Recall Task

The waves shown in Fig.5 are examples of $SERP_{kj}(t)$ ($k=1, j=1,2,3,4, t=1,2,\dots,1000$) obtained by averaging eighty measured data and by using the standard deviations of the EEG's, when "sub 1" recalling "ri-n-go" during her watch of the problem. The average EEG can be considered as a typical ERP. The arrows directing downwards or upwards indicate the potentials of ERP's. P_{100} and N_{200} are a kind of visual evoked potentials, P_{300} is the potentials concerned with the recognition of the problem, and N_{400} is considered as a potential related with the judgment from the context. Fig.6 is another example of $SERP_{kj}(t)$ ($k=2, j=1,2,3,4, t=1,2,\dots,1000$) obtained from "sub 2". The potentials of P_{100} , N_{200} , P_{300} and N_{400} also appear. The $SERP_{kj}(t)$ from "sub 1" and "sub 2" are a little different from each other, because the problems causing them are different from each other and the individual variation influences the potentials. Anyway, the $SERP_{kj}(t)$ ($j=1$) obtained by watching the problem is a bit different from the other for each subject: they have clearly positive and negative peaks after N_{400} . We call them P_{450} and N_{500} for "sub 1", and P_{500} and N_{550} for "sub 2".

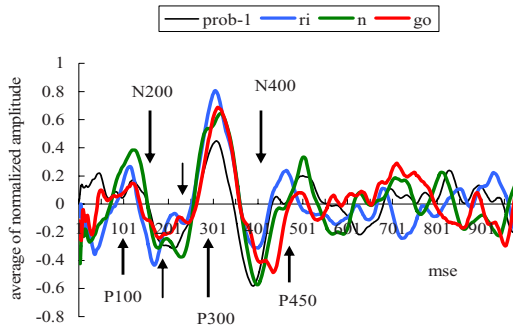


Fig. 5. An example of $SERP_{kj}(t)$ obtained by an Associative Recall Task (sub1, C3, recalling "ri-n-go")

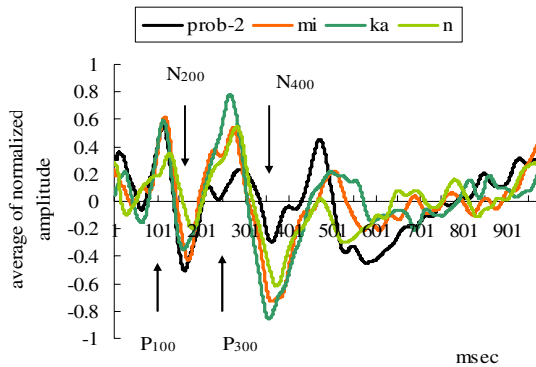


Fig. 6. An example of $SERP_{kj}(t)$ obtained by an Associative Recall Task (sub2, C3, recalling "mi-ka-n")

3.3 An ERP Obtained by a Syllable Recall Task

An example of an ERP obtained by a syllable recall task is shown in Fig.7. The potentials named P_{100} , N_{200} , P_{300} and N_{400} appear. It is estimated that the potentials exist about 450msec before the start. The ERP's contain various types of noise comparing with the ERP's in Fig.5 or in Fig.6. The reason why the noise remains is considered that the recalling syllable does not much depend on subjects but considerably depends on the the associative recalling task, the fruit name. Noise is also contained in the ERP's obtained from sub2.

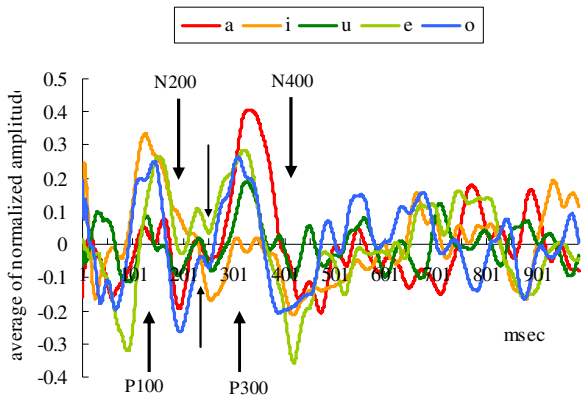


Fig. 7. An example of $SERP_{kj}(t)$ obtained by Syllable Recall Task (sub1, C3, recalling “a”, “i”, “u”, “e”, “o”)

3.4 Comparison Between the ERP's of Both the Types

In Fig. 8, two waves of “ERP(t)’s” obtained by the two types of the syllable recalling tasks are shown in the order of the syllables of a fruit name (“ri-n-go”), and these waves are compared. We use ERP's obtained by recalling “ko” instead of “go” in the the syllable recalling tasks, since we did not record pronounced consonants in the syllable recalling tasks. Each ERP(t) wave of the associative recalling tasks is the result of plotting the values during the time interval, [100-500msec]-section, and standardizing them in the section. Moreover, the latencies are adjusted beforehand so that the latencies of P_{300} obtained the syllable task overlapped with the correspondence of P_{300} obtained by the associative task, because the noise does not sufficiently attenuate in the ERP's obtained by the syllable tasks. After some arrangement, the ERPs of the one type resemble the other type very much, and our result shows the possibility of estimating recalling a fruit name through the ERP's.

The ERP's in Fig.9 do not resemble each other. The results show that the difficulty to estimate the recalled fruit name through the ERP's.

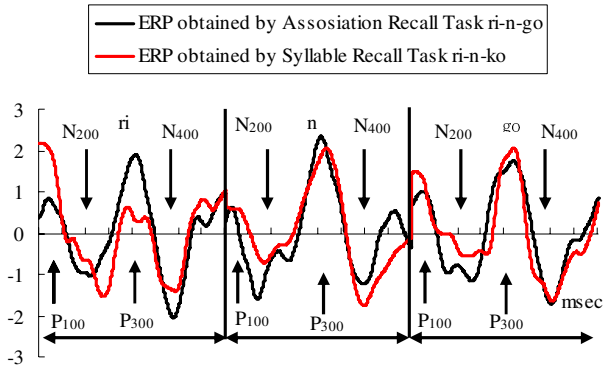


Fig. 8. Comparison between the ERP’s obtained by a syllable recall task and an associative Recall Task (sub1, C3, recalling “ri”, “n”, “ko”, and “ri-n-go”)

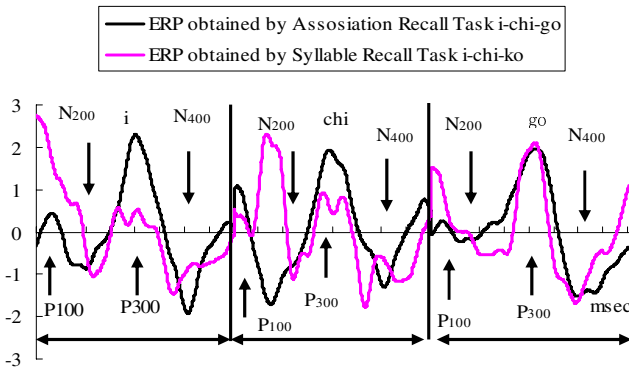


Fig. 9. Comparison between the ERP’s obtained by a syllable recall task and an associative recall task (sub1, C3, recalling “i”, “chi”, “ko”, and “i-chi-go”)

3.5 Estimation of a Fruit Name Through ERP’s

In order to estimate the recalled names of fruits, we use the following algorithm A. It uses the correlation between the ERPs in Fig.8 and Fig.9. The values of the correlation are 0.81 and 0.39 each in each type of the ERPs.

Table 1 shows the result of the detection ratio. If we use the average of the ERP’s obtained by an associative recalling task, the correct detection ration is about 91.3%. But in the case where ERPs by a syllable recalling task are used, the average of correct detection ratio is about 65%. The difference between these two cases is about 25%.

[Algorithm A]

Step 1: we take out the part of $ERP_{kj}(t)$ ($t=t1, t1+1, \dots, t2$) from all $ERP_{kj}(t)$, and normalize them. ($k=1,2,\dots,50, j=2,3,4$)

- Step 2: we select parts of $ERP_{kj}(t)$ caused by the syllables of fruits and concatenate them. We represent the concatenated data as $mihon_i(t)(i=1,2,\dots,5, t=1,2, \dots, 3(t2-t1+1))$
- Step 3: we take out the part of $ERP_{kj}(t)$ ($t=t1, t1+1, \dots, t2$) from all $ERP_{kj}(t)$, and normalize them. ($k=1,2,\dots,5, j=2,3,4$)
- Step 4: we concatenate the normalized parts of $ERP_{kj}(t)$ for $j=2,3$, and 4 for each k . We represent the concatenated data as $LERP_i(t)(i=1,2,\dots,5, t=1,2, \dots, 3(t2-t1+1))$
- Step 5: we calculate the correlation $r(i,j)$ between $mihon_i(t)$ and $LERP_j(t)$ ($t=1,2, \dots, 3(t2-t1+1)$) for all combinations i and j .
- Step 6: if $r(i,j)$ has the maximum value among $r(i,k_2)$ $k_2=1,2,\dots,5$ or if $r(i,j)$ has the maximum value among $r(k_1,j)$ $k_1=1,2,\dots,5$, we estimate the subject visualized the j th words.

Table 1. Detection Ratio by the Algorithm A*

subjects	mihon	item	1st experiment	2nd experiment	3rd experiment	4th experiment
sub1	Averaged ERP by Assosiation Recall Task	ratio of correct answer	100%	100%	100%	100%
		number of addition	20	10	20	40
	Averaged ERP by Syllable Recall Task	ratio of correct answer	80%	40%	80%	100%
		number of addition	20	20	20	40
sub2	Averaged ERP by Assosiation Recall Task	ratio of correct answer	100%	40%	100%	80%
		number of addition	20	20	20	20
	Averaged ERP by Syllable Recall Task	ratio of correct answer	80%	40%	60%	40%
		number of addition	20	20	20	20

* Since we were not able to do the final experiment about sub1, the ERPs of the 4th experiment are the average of ERPs obtained at the 1st and the 3rd experiment.

4 Discussion

We discuss the features of ERP's and the effectiveness of the algorithm A.

The correlations given in Fig.10 shows how much the ERP's obtained by recalling "na" resemble the ERPs recalling the syllable of a fruit. The ERPs obtained by recalling "na" in a fruit name has high correlation with the ERPs of a task of the other type. This shows the possibility to estimate a recalling word through ERP's. However, the ERP's of recalling "n" have higher correlation with the ERP's recalling "na". This result explains the difficulties of the estimation. By the way, the algorithm A dose not use ERP's to estimate a fruit name, but it uses the linked ERPs. This means the algorithm is suitable for unstable data as shown in Fig.10.

Let us consider the arrangement of latencies. The ERPs in Fig.11 (a) shows the ERPs before the arrangement of latencies, and the ERPs in Fig.11 (b) are the ERPs after the arrangement. The comparison between the ERPs shows that some arrangement of latencies is required to estimate a fruit name. The latencies of ERPs by a syllable recalling task are observed about 10msec - 30msec later than the those by an associative recalling task. One of the reasons why this delay occurs is the length of problems. The phrases of the poem is 4 times longer than the problem of the associative recall task. A longer phrase requires more time to recognize them than a shorter one.

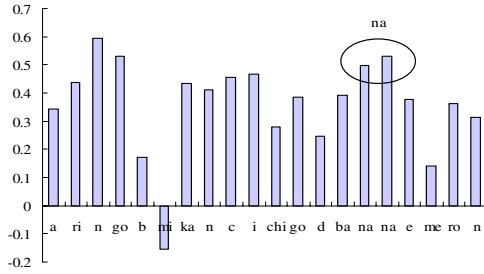


Fig. 10. Correlation between ERP obtained by recalling "na" and recalling fruit name

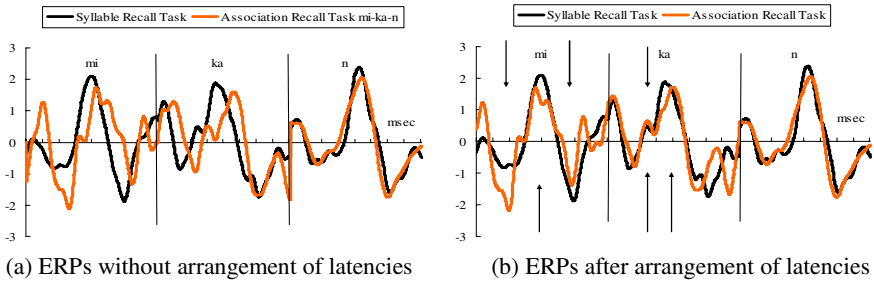


Fig. 11. ERPs obtained by recalling "mi-kan-n" and "mi", "ka", and "n"

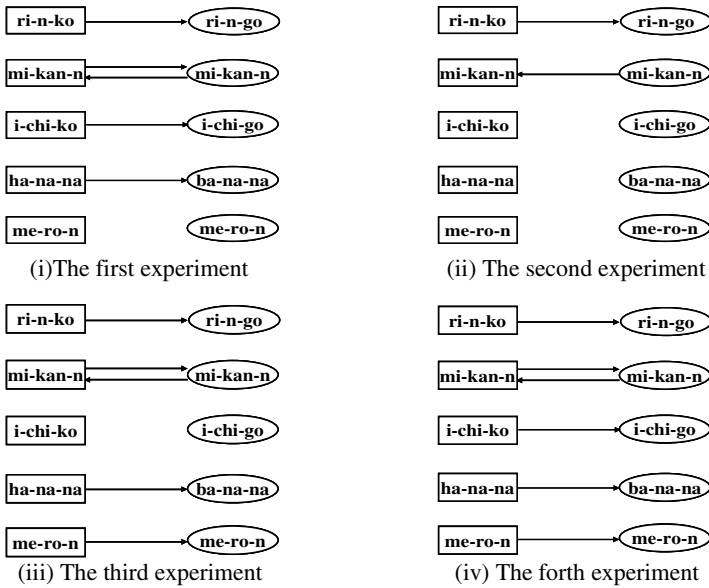


Fig. 12. The rule used in Algorithm A to estimate a fruit name (sub1, C₃)

Fig.12 shows the rules used in the algorithm A to detect a correct fruit name. The rectangle means the ERP's obtained by the syllable task, and the oval means the ERP's obtained by the associative task. The arrow shows the direction of the capability of the detection. In the fourth case, all fruit names are detected correctly. The result shows the possibility of estimation of words or statements by using ERPs

5 Conclusion

The analysis of the experimental data and our claims are summarized as follows:

- (1) We define "recall" as silent "pronunciation" without "tongue" moving. ERPs are caused by recalling the words. The words used in the experiments are five kinds of fruit in Japanese. ERPs caused by all Japanese syllable are measured.
- (2) Most meaningfully potential of ERPs for the estimation appears in the period [100msec, 550msec].
- (3) Potential N_{400} - P_{450} - N_{500} (or N_{400} - P_{500} - N_{550}) appears when the subjects determine the recalling words.
- (4) The words of fruits are almost completely estimated by the average of ERPs recalling them.
- (5) It is difficult to estimate the recalled fruits by the linked ERPs caused by a syllable recall task, however it is not impossible.

The number of subjects in our experiments is too small. We must increase it to evaluate fairly our methods. We need further investigation to devise more effective methods to estimate the recalling words or statements.

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