ERP-based Speller with a New Paradigm

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Abstract: In most implementation of an ERP-based speller, standard row-column paradigm (RCP) was used. However, RCP is susceptible to adjacency-distraction errors because items in the same row or column of the target flash at the time of a half when the target item flashes. The adjacency-distraction errors could be reduced if the number of flanking items that flash with the target is diminished. This study presents a novel P300-based stimulus presentation called row-column-diagonal paradigm (RCDP) where characters on the main diagonal and the anti-diagonal in the matrix flash in addition to characters on the row and columns. In RCDP, items in the same row, column, main diagonal, and anti-diagonal of the target flashes at the time of a quarter when the target item flashes. Using a 6×6 matrix of alphanumeric characters and keyboard commands, ten college students used RCP and RCDP. Stepwise linear discriminant analysis (SWLDA) for the EEG signals recorded in calibration phases was used to calculate discrimininant function. By applying the discrimininant function to electroencephalography (EEG) signal recorded in the test phase, the probability whether the item was the target or not was evaluated. Average accuracy was 76.6% in RCP while 84.0% in RCDP. With RCP, most errors were occurred in the same row or column of the target; on the other hand, with RCDP in the same row, column, main diagonal, or anti-diagonal of the target. These findings indicate how RCDP reduces adjacency-distraction errors and might be able to contribute to develop more advanced stimulus presentation paradigm.

1 INTRODUCTION

Although it had been almost impossible for the paralyzed patients to communicate with others and to control any devices, Farwell and Donchin (1988) introduced an innovative invention for them to communicate by using electroencephalography. The invention was the first speller paradigm that is to write characters in a computer by using event-related potential (ERP). In this paradigm, a computer presents a 6 × 6 matrix of letters on screen as shown in Fig 1 (A) and groups of matrix items flash randomly. Twenty trials should be performed in this paradigm to spell one character where one sequence consisted of the six rows in the matrix flash in order followed by the six columns in the matrix flash. There participants are asked to attend to the item they wish to select or count the number of times the item flashes.

The amplitude of P300, one of the ERP components increases when a participant attends to the item. If a computer calculate the P300 amplitude of users when a item flash, the computer is able to identify the attended item as the intersection of the row and column that elicited the largest P300. Due to the P300 response′s relatively low signal-to-noise ratio, each item must be flashed multiple times and the results averaged. The number of times the item flashes is positively correlated with average accuracy (Donchin et al., 2000; Lenhardt et al., 2008). The more each item flashes, the less ERP noise occur and the higher accuracy become. On the other hand, the more each item flashes, the longer time for presentation becomes for a participant to spell a character.

The novel paradigm developed by Farwell and Donchin(1988) is called the row column paradigm, or RCP since items are grouped for flashing as rows and columns. However, the RCP remains subject to errors and, importantly, these errors appear to have one primary cause (Fazel-Rezai, 2007; Fazel-Rezai et al., 2012; Townsend et al., 2010). Errors typically occur with the greatest frequency in locations adjacent to the attended item (i.e., the target item) and almost always in the same row or column. This inherent RCP error occurs because adjacent item flashes, it attracts the participants' attention

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(Townsend et al., 2010). We refer to these relatively systematic errors as adjacency-distraction errors". There is additional cause in RCP for the occurrence of adjacency-distraction errors because items in the same row or column of the target flash at the time of a half when the target item flashes. It consequently results in ERP response.

This study is to investigate a novel stimulus presentation paradigm that can control adjacency-distraction errors by reducing the number of flanking items that flash with the target. In the new paradigm as shown in Figure 1 (B), the target item on the main diagonal in the matrix flash in order followed by the anti-diagonal in the matrix. The paradigm is called row-column-diagonal paradigm (RCDP). With RCP, items are grouped for flashing as 6 rows and 6 columns in one trial. Items are grouped for flashing as 6 rows, 6 columns, 6 main diagonal, and 6 anti-diagonal in one trial with RCDP.

In RCP, items in the same row or column of the target flashes at the time of a half when the target item flashes while in RCDP, items in the same row, column, main diagonal, and anti-diagonal of the target flashes at the time of a quarter when the target item flashes. In this study, we hypothesized that the RCDP will produce superior performance as compared to the RCP because it diminishes the adjacency-distraction errors to which the RCP is prone.

2 METHOD

2.1 Participants

10 college students (5 males) participated in this experiment and their mean age was 24.4 years (range 22-28). They had no experience to participate in ERP-based speller experiment before. They had normal or corrected-to-normal vision.

2.2 Equipment

Each participant sat in a comfortable chair approximately 60 cm from a 19 inch LCD monitor with a 1280×1024 resolution that displayed the 6×6 matrix. The width of each character included in the matrix was 1.1cm and height was 1.3cm and the space between characters was 5cm on the right and left, 3cm on the top and bottom. According to Krusienski et al., (2008) results, EEG activity was recorded from Fz, Cz, Pz, Oz, P3, P4, PO7, and PO8. Linked electrodes attached to the mastoids served as reference and the ground electrode was placed at the forehead. The signals were amplified using a Grass Model 12 Neurodata Acquisition System (Grass Instruments, Quincy, MA, USA) (high-pass and low-pass filters 0.3 and 30Hz, respectively) with 20000 amplification rate. EEG was recorded by bio-amplifier MP150 (BioPac Systems Inc., Santa Barbara, CA, USA) and the signals were saved at the sampling rate of 200Hz. Recording programs for stimulus presentation and EEG activity was created via visual C++ v6.

2.3 Experimental Procedure

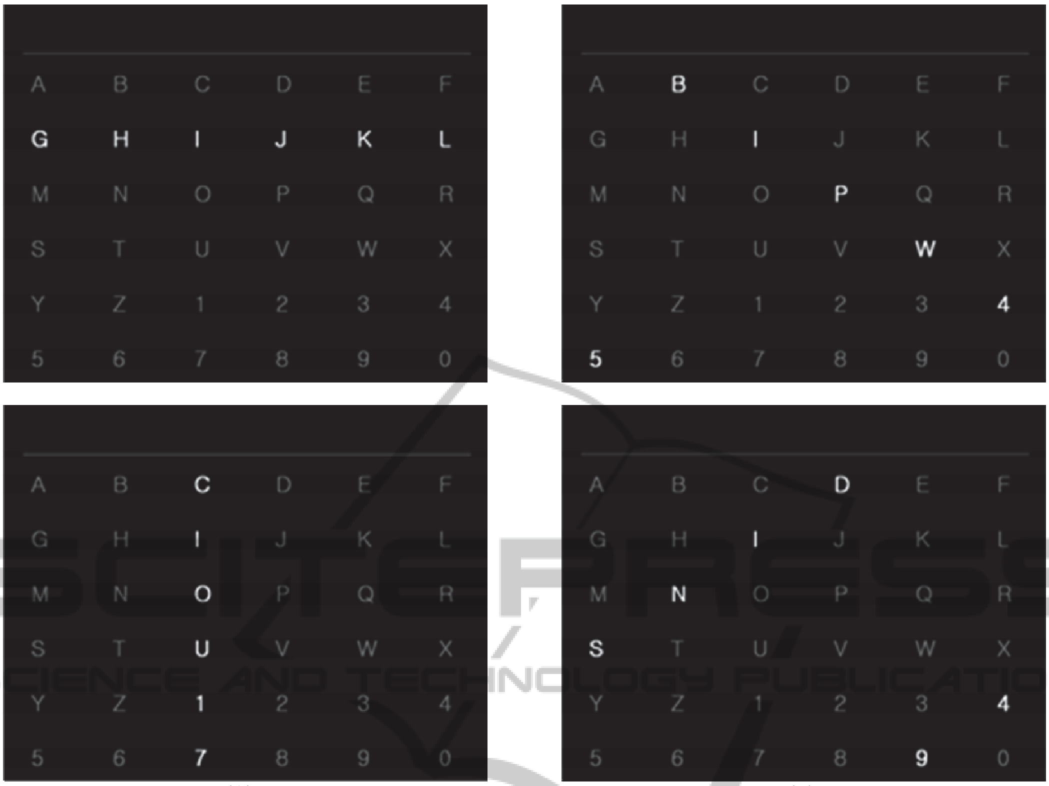
Each participant completed two experimental sessions. Sessions began with the RCP session and the RCDP session followed. Each session consisted of a calibration phase and an test phase. The first phase was a calibration phase to generate discrimininant function for identifying target item. The second phase was a test phase for detecting the target item by applying the discrimininant function.

Total 18 items were used in a calibration phase and 25 items consisted of rows having 5 characters and 1 number in a test phase. In RCP, one row or column from the 6×6 matrix flashes once at a time in a random order. The participant's task was to attend to (or count) the number of times the item in a row or column flashed.

When spelling a character, one trial is defined where 6 rows and 6 columns flashes all once at a time and total 6 trials were repeated. In RCDP, 6 rows, 6 columns, 6 main diagonal, and 6 anti-diagonal flash in a random order. In RCDP, one trial is defined where, 6 rows, 6 columns, 6 main diagonal, and 6 anti-diagonal flashes all once at a time and total 3 trials were repeated. In both RCP and RCDP, each set of items flashed for 100ms followed by a 25ms inter-stimulus interval. Sessions were counterbalanced to minimize the effect of the order. After completing both sessions, participants were asked to rate about how difficult it was when performing each type of paradigm on 7-point Likert scale, with 1=Very difficult and 7=Very easy.

2.4 Classification

Stepwise linear discriminant analysis (SWLDA) for the EEG signals recorded in calibration phases was used to calculate discrimininant function. The probability whether the item was the target or not was calculated by applying the discrimininant function to EEG signal recorded in the test phase.



(A) (B)

Figure 1: (A) Row-column paradigm. (B) Row-column and diagonal paradigm.

SWLDA was conducted as follows. When spelling a character, rows and columns flash 72 times (In RCDP, rows, columns, main diagonal, and anti-diagonal) flashed. During this period, EEG activity was recorded from 8 scalp locations. After a set of items start to flash, 750ms data segment was created. Seventy-two segments were made while one character flashes. One segment recorded from an electrode consists of 150 values (750ms × 200Hz).

These segments are distinguished in case where the target item is included from where the target item is not included. As a result, a matrix having 72 × 18 columns and 150 × 8 rows was created, and discriminant function that can distinguish target item from non-target item was calculated by conducting SWLDA

In test phase, an participant spell a character ERP was calculated for the each 36 characters on the 36 × 1200 matrix by averaging EEG segment recorded while each item flickers.

The probabilities whether the column was the target or not was calculated by applying the disciminninant function for the 36 columns. The item that shows the highest probability was selected as target characters.

2.5 Transfer Rate

A possible method for evaluating the speller function is the amount of information that is conveyed per time unit, also known as data transfer rate or bit rate. The written symbol rate (WSR) can be determined by first computing the bits (B) per trial and then the symbol rate (SR; see below the fomula 1)

$$B = log_2 N + P log_2 P + (1-P) log_2 \left(\frac{1-P}{N-1}\right) \quad (1)$$

N is the number of possible targets and P is the probability that the target is accurately classified. Then from equation (1) the symbol rate is determined as,

$$SR = \frac{B}{log_2 N} \quad (2)$$

If T is the trial duration in minutes, the WSR can be determined as follows:

$$WSR = \begin{cases} \frac{2SR-1}{T} & SR > 0.5 \\ 0 & SR \leq 0.5 \end{cases} \quad (3)$$

3 RESULTS

Table 1 shows accuracy, B, and WSR. Average accuracy was 72.8% in RCP while 83.2% in RCDP. The RCDP was significantly more correct in P300 speller performance than the RCP($t(9)=2.57$, $p<.05$). B was significantly lower in RCP as of 20.3% than in RCDP as of 25.3%.($t(9)=2.58$, $p<.05$). The WSR in RCDP as of 3.5 was significantly higher in RCP as of 1.8 ($t(9)=2.35$, $p<.05$).

In the individual data, eight out of ten participants showed higher accuracy in RCDP than in RCP, one showed the same accuracy in both paradigms, and the last one showed higher accuracy in RCP than in RCDP. Figure 2 represent errors occurring in each cell relative to the target location. Sixty-eight errors were occurred in RCP where 62 out of them (91%) occurred in the same row or column of the target. Forty-two errors were occurred in RCDP where 35 out of them (83%) occurred in the same row, column, main diagonal, or anti-diagonal of the target.

When the participants rated about how difficult it was when using each type of paradigm, their mean score was 5.1 in RCP and 4.9 in RCDP. There was no significantly difference ($t(9)=.557$, n.s.).

4 CONCLUSIONS

ERP-based speller by using RCP is susceptible to adjacency-distraction errors. This study presents a alternative P300-based stimulus presentation–RCDP to avoid the errors and examine average accuracy. The results showed that, as we hypothesized, the RCDP was more correct in P300 speller performance than the RCDP.

Average accuracy was 72.8% in RCP while 83.2% in RCDP. Guger et al. (2009) reported 91% of average accuracy in RCP based on the findings from offline experiment among 81 healthy subjects. It was higher than the result of this study, and the reason might be the number of trials they used, 20 trials for a character. If the number of trials in RCDP is calculated to that of RCP, RCDP uses 6 trials for a character. When the number of trials increases, the accuracy rate becomes greater (Furdea, 2009). Thus, if the same number of trials is used for RCDP, it will result higher accuracy than that of RCP.

Townsend et al. (2010) compared accuracy rate of RCP to that of checkerboard paradigm (CBP), an alternative paradigm which they designed. When 3 or 5 trials were used, average accuracy was 77.3% in RCP while 91.5% in CBP. They found that the CBP yielded higher accuracy than that of the RCDP. There are two main reasons for higher accuracy of CBP than the RCDP. Firstly, this study used an 6×6 matrix, while Townsend et al. (2010) used 8×9 matrix. The 6×6 matrix needs to be flashed 6 times to intensify each character, whereas the 8×9 needs to be flashed 12 times. Thus, inter-target interval (ITI) of CBP becomes longer by using 8×9 matrix than that of RCDP that uses 6×6 matrix. When the ITI becomes longer than 5 seconds, ITI does not affect P300 amplitude (Rasmusson and Allen 1994). However, when the ITI is shorter than 1 second, ITI affect P300 amplitude. P300 responses to the current target elapse since the responses overlapped with those of the previous target.

For this reason, in CBP where ITI is more than one second, P300 amplitude becomes larger and accuracy rate increases. Secondly, CBP controls double-flash error effectively. Although RCDP is efficient for controlling adjacency-distraction errors, it still has double-flash problem.

Table 1: Values of accuracies and bit rates (bits/min) for the RCP and RCDP.

Participant	RCP			RCDP		
	Accuracy	Bit rate	WSR	Accuracy	Bit rate	WSR
1	68.0	17.5	0.1	96.0	31.5	5.5
2	92.0	29.0	4.6	100.0	34.5	6.7
3	48.0	10.0	0.0	52.0	11.4	0.0
4	80.0	22.8	2.2	88.0	26.8	3.7
5	64.0	15.9	0.0	64.0	15.9	0.0
6	92.0	29.0	4.6	88.0	26.8	3.7
7	68.0	17.5	0.1	92.0	29.0	4.6
8	56.0	12.8	0.0	88.0	26.8	3.7
9	100.0	34.5	6.7	100.0	34.5	6.7
10	60.0	14.3	0.0	64.0	15.9	0.0
Mean	72.8	20.3	1.8	83.2	25.3	3.5

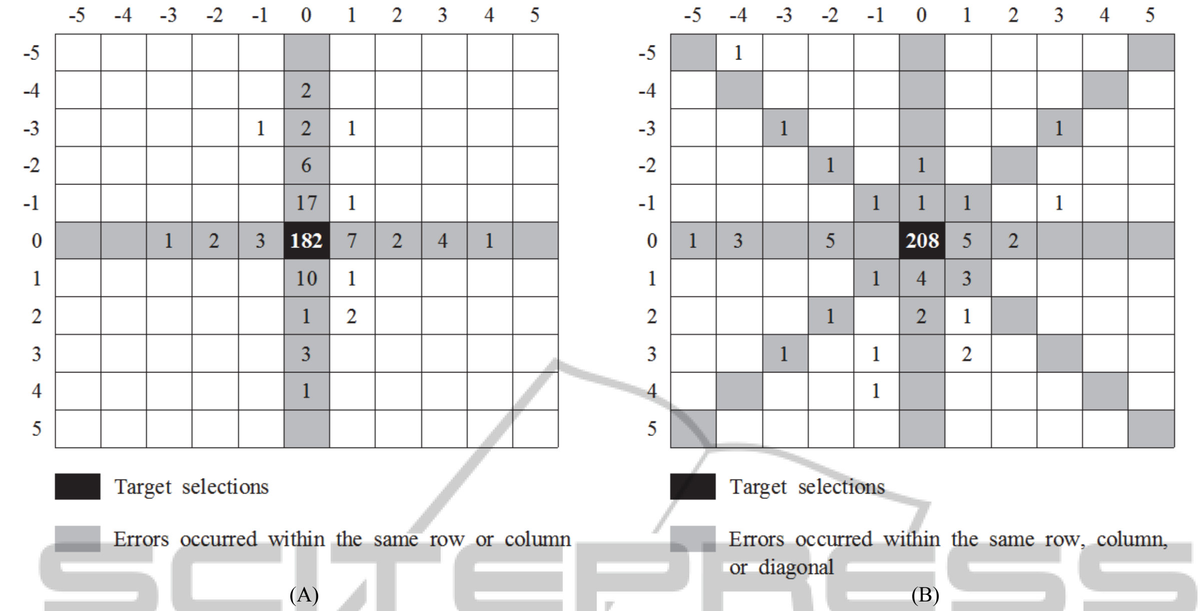


Figure 2: (A) Error (A) Error distributions for the RCP. (B) Error distributions for the RCDP. All target items have been centered in each matrix; the number in the black cell is the number of correct selections for each paradigm. Numbers in other cells represent the number of errors occurring in each cell relative to the target location.

One advantage of RCDP compared to CBP is that it uses smaller matrix. By using smaller matrix, RCDP needs less number of trials for spelling an item compared to CBD which uses larger matrix.

The results of an error analysis from the RCP were consistent with previous studies (Fazel-Rezai, 2007; Townsend et al., 2010). More than 90% of errors were occurred in the same row or column of the target. In RCP, items in the same row or column of the target flash at a rate of 50% when the target item flashes. On the other hand, in RCDP items in the same row or column of the target flash at a rate of 25% at most when the target item flashes. Consequently, this novel paradigm reduced adjacency-distraction errors by diminishing the flickering frequency for adjacent items to the target item when the target item flashes.

The performance accuracy is highly related to the flickering frequency of the each character. To sustain the stable accuracy, trials should be repeated less in RCDP while the trials should be repeated more in RCP. These findings suggest how RCDP reduces adjacency-distraction errors and might be able to contribute to develop better stimulus presentation paradigm.

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