THE MENTAL PROSTHESIS: ASSESSING THE SPEED OF A P300-BASED BRAIN-COMPUTER INTERFACE

K. M. Spencer, O. Karni, R. Wijesinghe, and E. Donchin
Department of Psychology and Beckman Institute, University of Illinois at Urbana-Champaign
(Presented at the Society of Psychophysiological Research, 1998, Denver, Co.)

Introduction

Farwell and Donchin (1988) described a Brain Computer Interface (BCI; Vaughan, Wolpaw, & Donchin, 1996) that exploited the properties of the oddball paradigm to allow a user to communicate a sequence of letters to a computer by observing a continually displayed matrix of characters (Figure 1), and focusing attention successively on the characters to be communicated.

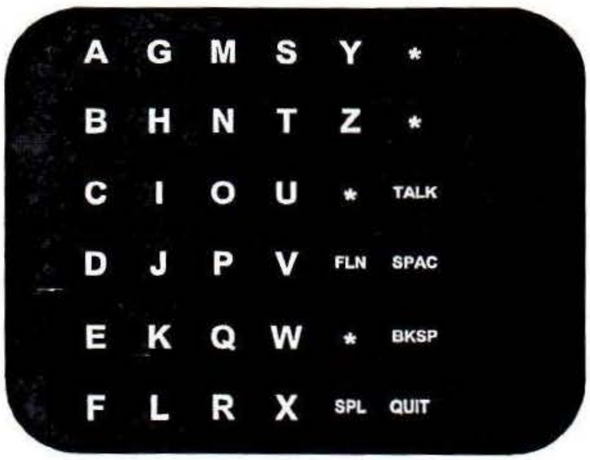

Figure 1 Display presented to the subject. The rows and columns of the matrix are intensified in a random sequence for 100 msec.

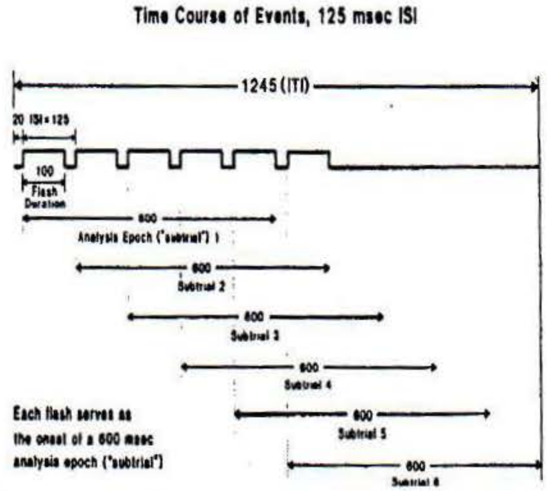

Fig 2. Sequence of events in a trial (From Farwell and Donchin, 1998).

An oddball sequence was produced by intensifying, in a random sequence, each of the 6 rows and 6 columns of the matrix. Each intensification lasted 100 ms, with and SOA of 125ms. The interval between trials (6 row and 6 column intensifications) was 1500ms. (See Fig. 2 for details.)

Farwell and Donchin hypothesized that the rows and columns that contain the character to which the subject is attending will constitute a distinct category among the stimuli and, being rare, will elicit a P300.

The BCI used the following procedure:
1. Obtain a 600 ms record of the EEG following each of the intensifications.
2. Compute the ERP associated with each row and with each column.
3. Intensifications of the row and column containing the target character elicit easily detectable P300s.
4. No P300s are elicited by the intensifications of rows and columns that do not contain the target.

The P300 was easy to detect when the data associated with 40 trials were averaged. Thus, 100% correct communication can be achieved if enough time is allocated for each character. Naturally, a practical BCI should provide faster communication. The speed depends on the number of trials required for an accurate detection of the P300 (see Table 1).

N trials	1	2	4	5	16	32
Communication rate Items per minute)	40	20	10	5	2.5	1.25

The Current Study

Under the circumstances of the system used by Farwell and Donchin (1988), the system was able to operate at maximum rate of about 8-10 characters per minute. While under some circumstances this is an acceptable rate, it was our goal to capitalize on the increased computational power currently available to determine if we can improve the rate of transmission. The current BCI was implemented in a Wintel system, using a Gateway 2000 PC.

Figure 3. Revised version of display. Note the elimination of the replacement of operating codes with the nine digits.

Methods

Subjects

10 able-bodied (6 female) and 4 disabled subjects (wheelchair-bound; 3 with complete paraplegia, 1 incomplete paraplegia; 2 female) from the university community participated in the experiment.

Stimuli and Procedure

1. Stimuli and procedures were the same as in Farwell and Donchin (1988; see Introduction).
2. A modified version of the display was used (Fig. 3).
3. A trial is a sequence of 6 row and 6 column intensifications.
4. Inter-trial interval was 2500 ms (1500 ms + 1000 ms pause, inserted for technical reasons).
5. Subjects were instructed to count the number of times the row or column containing the target letter "P" was intensified.
6. P(Target) = 2/12 = 0.167
7. Each subject performed 5 blocks of 15 trials each.

Data Acquisition and Processing

1. EEG was recorded with Biologic amplifiers (0.01 - 100 Hz passband, 200 Hz digitization).
2. Electrode sites were Fz, Cz, Pz, O1, O2, and right mastoid, referenced to left mastoid, re-referenced off-line to averaged mastoids.
3. Vertical and horizontal EOG artifacts were removed from the EEG by an eye-movement correction method.

Single-trial epochs for each cell of the display matrix were derived by averaging together each combination of row and column single-trial epochs. Thus, there were 6 rows X 6 columns = 36 epochs for each trial.

Grand Average ERPs

As can be seen in Fig. 4, the targets elicit a large P300. The ERPs for "Target Letter" were associated with the cell at the intersection of the correct row and correct column. The ERPs for "Target Row/Column" were associated with the cells at the intersection of the correct row or column, and an incorrect column or row, respectively

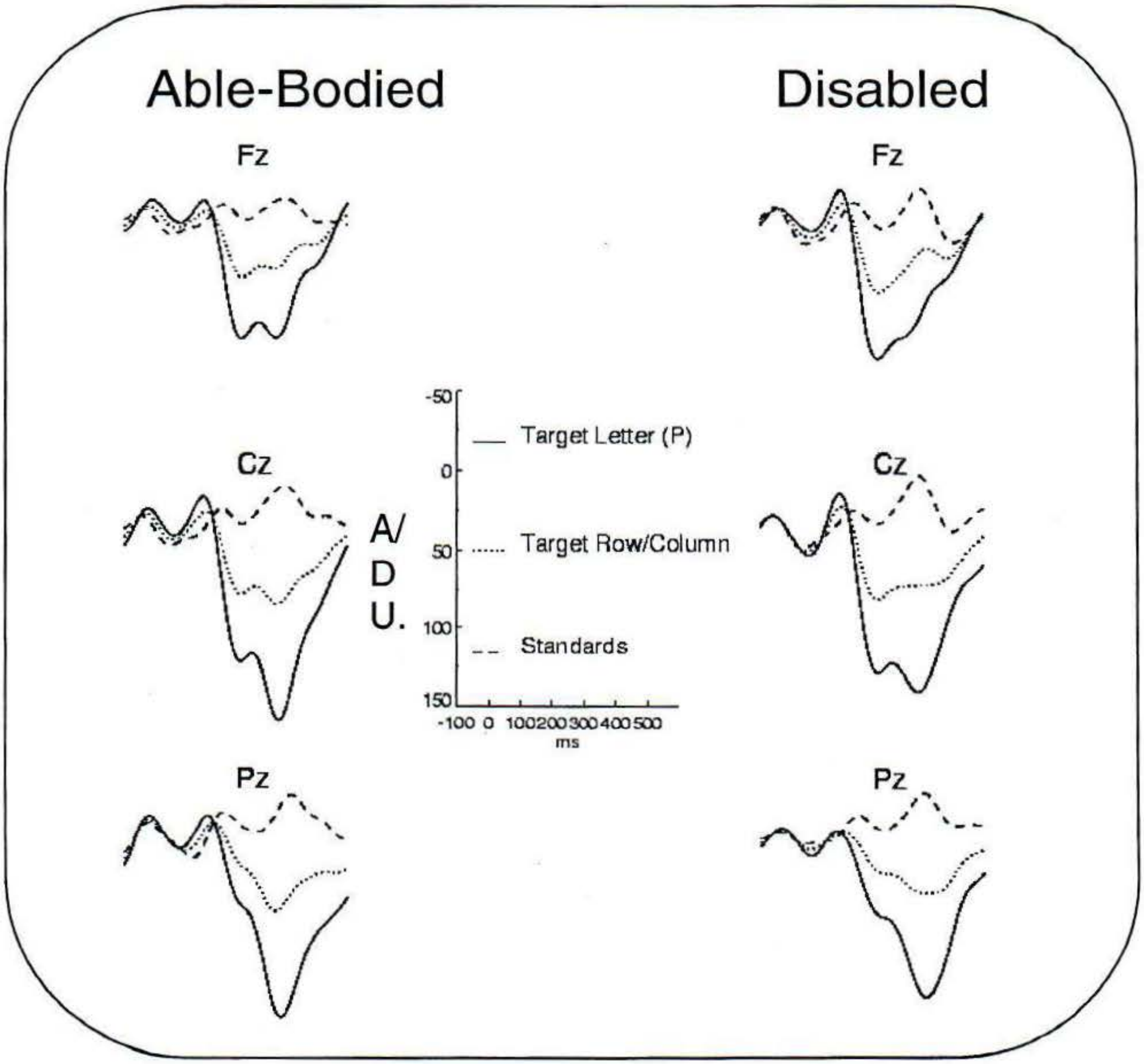

Fig.4

Bootstrap Analyses

Stepwise discriminant analysis (SWDA) was applied to a data set constructed by bootstrapping to assess the accuracy with which the target cell was detected as a function of the number of trials used for averaging. This procedure was applied with two pre-processing methods:

1. SWDA: Single-trial cell epochs were filtered at 0-8 Hz and resampled at 50 Hz, yielding 30 timepoints for the 0-600 ms period of each epoch.
2. SWDA/DWT: Single-trial cell epochs were filtered at 0-50 Hz and resampled at 50 Hz, yielding 32 time points for the 0-640 ms period. These timepoints were converted to wavelet coefficients with the Discrete Wavelet Transform (DWT).

Bootstrapping Procedure

To assess the accuracy given N trials (see Table 1), repeat the following procedure 1000 times:

1. Obtain a random sample of N trials for each cell by sampling w/replacement from the set of 75 trials.
2. Compute the average of N trials for each cell.
3. Apply SWDA to the set of cell averages.
4. Compute the discriminant score for each cell.
5. Select the cell with the maximum discriminant score.
6. If the selected cell is the defined target cell, count a hit, otherwise count a miss.

When done, record the percentage of hits among the 1000 samplings. This is the percent accuracy at the communication speed determined by the N trials.

(These values assume that the BCI can proceed with no delay between trials. In the current implementation of the BCI, technical considerations dictated a 1000 ms pause between trials.)

Table 2

		Accuracy Level	
Subject	Pre-processing	80%	95%
Able-Bodied	**SWDA**	**6.3 items/min**	**3.4 items/min**
	SWDA/DWT	**7.8 items/min**	**4.3 items/min**
Disabled	**SWDA**	**4.8 items/min**	**2.8 items/min**
	SWDA/DWT	**5.9 items/min**	**3.2 items/min**

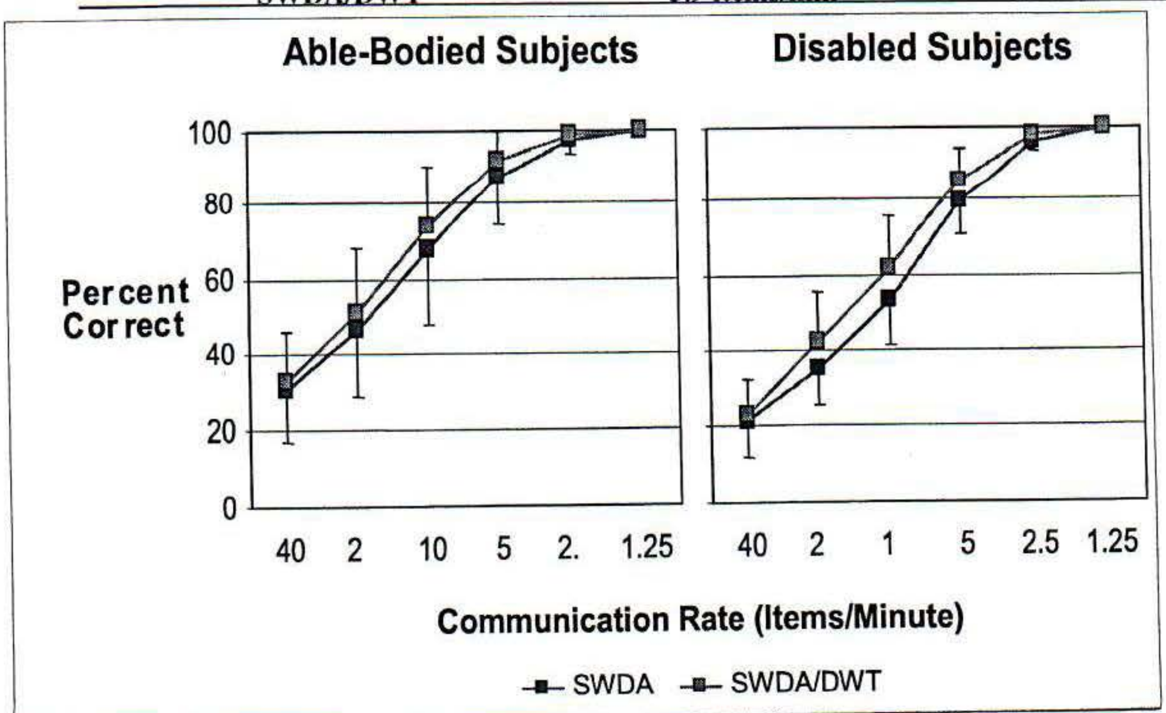

Figure 5: Faster communication rates were obtained with the Able-Bodied subjects than with the Disabled subjects. Furthermore, the SWDA/DWT pre-processing method produced somewhat faster communication rates than the SWDA method. (See Fig. 5 and Table 2.)

Online Test

Five of the 10 able-bodied subjects participated in a test of the ability of the BCI to detect characters online and in real time.

Each subject was run first in the bootstrap analyses to calibrate the BCI (see above). In the online test, each subject selected successively 5 individual characters. Using discriminant scores based on the number of trials required to reach 90% accuracy in the SWDA analysis, the BCI selected a character which appeared to match the character selected by the subject. The logical flow is presented below (Fig. 6):

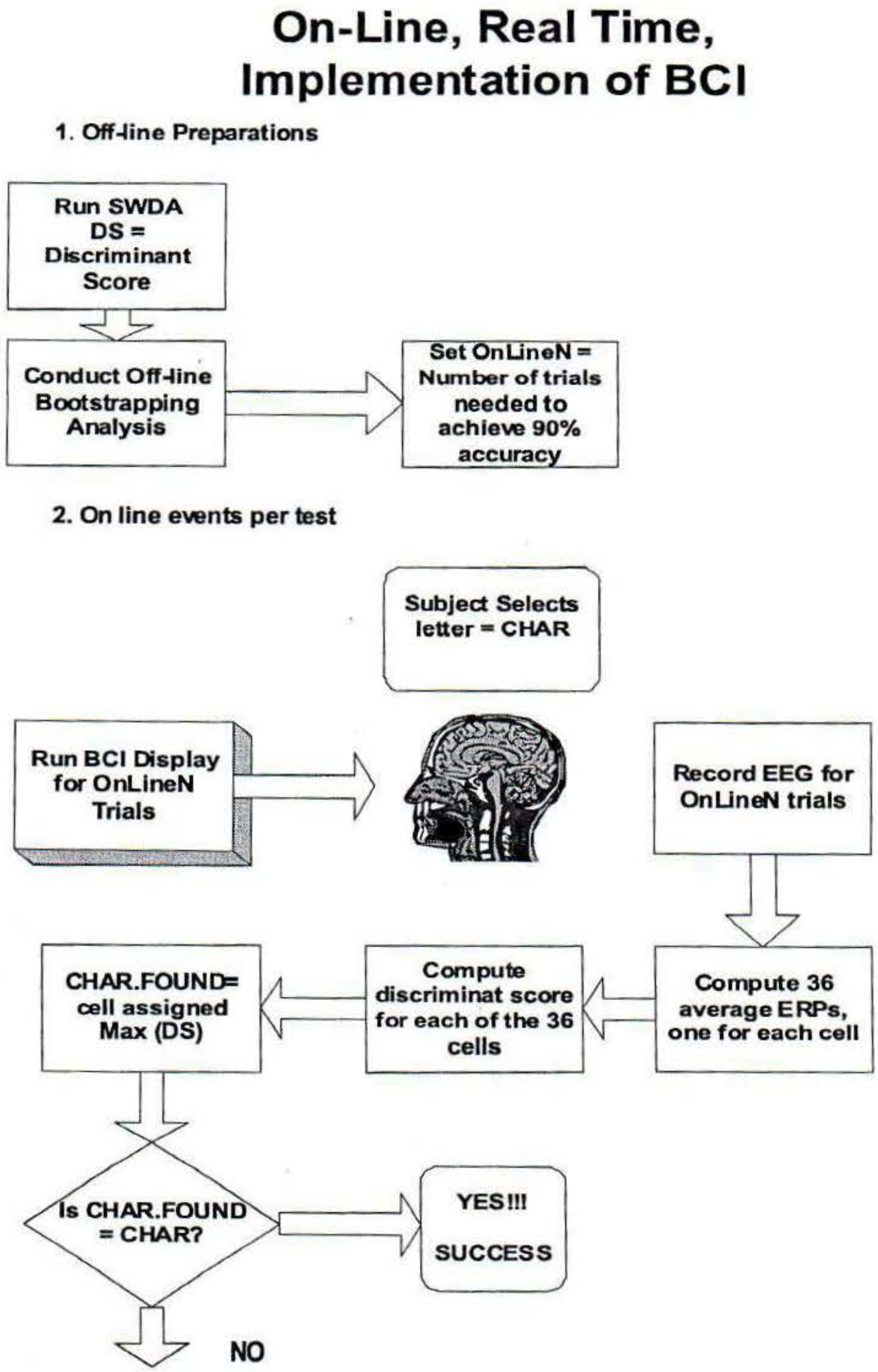

Figure 6

Online Test Results

Averaging the number of trials that produced 90% accuracy in the SWDA analysis for the online test, the BCI identified the cell to which the subject was attending 56% of the time. On 36% of the cells, the BCI chose the correct row or column. For only 8% of the cells the BCI chose incorrect row/column combinations. (See Table 3.)

Correct Cell	Correct Row/Column	Incorrect Cell
56 %	36 %	8 %

Table 3

Conclusions

We confirm the report by Farwell and Donchin (1988) that it is possible to construct a Brain Computer Interface that, using the P300, allows an individual to operate a virtual keyboard without using or requiring any activation of skeletal muscles.

The speed of the BCI used in this study is substantially faster than that used by Farwell and Donchin. The factors accounting for the speedier action are:

1. Improved SWDA algorithms in commercially available packages.
2. The use of the Discrete Wavelet Transform.
3. The application of the Discriminant function to the 36 individual cells.

The current study also tested the feasibility of the P300 based BCI with wheel-chair bound individuals with encouraging results.

Assessment

In evaluating the speed of the P300-based BCI it is important to recall that the device is intended for use by individuals who are completely disabled. As a base of comparison one needs to use the communication method used by Bauby (1997), a "locked-in" patient, to write his book, "The Diving-Bell and the Butterfly".

References

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Acknowledgments

This study was supported by a grant from the Campus Research Initiatives Program at UIUC and by STTR grant 1 R41 MH56319-01 to Biologic Systems Inc, in collaboration with UIUC.