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# Development of a Hybrid Mental Speller Combining EEG-Based Brain-Computer Interface and Webcam-Based Eye-Tracking

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*Abstract*— **The main goal of this study was to develop a hybrid mental spelling system combining a steady-state visual evoked potential (SSVEP)-based brain-computer interface (BCI) technology and a webcam-based eye-tracker, which utilizes information from the brain electrical activity and eye gaze direction at the same time. In the hybrid mental spelling system, a character decoded using SSVEP was not typed if the position of the selected character was not matched with the eye direction information ('left' or 'right') obtained from the eye-tracker. Thus, the users did not need to correct a misspelled character using a 'BACKSPACE' key. To verify the feasibility of the developed hybrid mental spelling system, we conducted online experiments with ten healthy participants. Each participant was asked to type 15 English words consisting of 68 characters. As a result, 16.6 typing errors could be prevented on average, demonstrating that the implemented hybrid mental spelling system could enhance the practicality of our mental spelling system.**

## I. Introduction

People suffering from serious neurological disorders such as amyotrophic lateral sclerosis (ALS), brainstem stroke, and spinal cord injury have difficulties in communicating with other people. Brain-computer interface (BCI) is a non-muscular communication method that allows them to communicate with the outside world using external devices operated by their brain activities [1].

To implement practical BCI systems, various neuroimaging modalities have been used, such as electroencephalography (EEG) [2], magnetoencephalography (MEG) [3], electrocorticography (ECoG) [4], near-infrared spectroscopy (NIRS) [5], and functional magnetic resonance imaging (fMRI) [6]. Among them, EEG has been most frequently used. One of the most representative EEG-based BCI applications is the BCI speller, which allows disabled people to express their thoughts by simply attending on target characters. Mental spellers based on brain signals have advantages over eye-tracker-based spellers in that they do not require any calibration procedures before the applications. Moreover, the eye-tracker-based spellers sometimes can hardly be applied to patients with lowered oculomotor functions due to neurodegenerative disorders such as ALS.

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In our previous study [7], we introduced a mental spelling system based on steady-state visual evoked potential (SSVEP) (See Fig. 1). When using the developed mental spelling system, the user was supposed to gaze at a target character flickering with a certain frequency to spell a character. Our mental spelling system then detected the target character by investigating the changes in the SSVEP responses. As a result of online experiments, we attained an average typing speed of 9.39 letters per minute (LPM) with an average success rate of 87.58 %.

Despite the high performance of our previous mental spelling system, typing errors sometimes occurred. In particular, some characters distant from a target character were frequently typed because we separated two LEDs with similar flickering frequencies as distantly located as possible [7]. Therefore, the goal of the present study was to enhance the performance of our previous mental spelling system by preventing some typos in advance. To this end, we combined the SSVEP-based mental speller with a webcam-based eye tracker that can estimate eye-gaze directions ('left' or 'right') without any calibration. To demonstrate the feasibility of our hybrid mental spelling system, online experiments were conducted with ten participants.

## II. Methods

### A. SSVEP-Based Mental Spelling System

A modified QWERTY keyboard layout was used as shown in Fig. 1. Thirty keys were placed as similarly as possible to a conventional QWERTY layout. Twenty-six keys were assigned to each of the English alphabet letters and the other four keys were assigned to BACKSPACE, ENTER, PUNCTUATION, and SPACE. The area of each key except ENTER and SPACE was 2 cm × 2 cm, and the distances between neighboring keys were 2.5 cm both horizontally and vertically. Thirty frequencies divided with a span of 0.1 Hz from frequency band of 5–7.9 Hz were empirically selected as flickering frequencies of each key [7]. To decode the user's

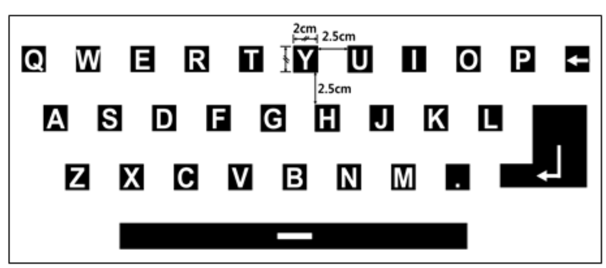


Fig. 1. The modified QWERTY keyboard layout.

intentions using SSVEP responses, we used a simple classification algorithm, which found a frequency with the largest SSVEP response. See [7] for details, and visit the following website to watch the movies of the online experiments performed with the previous mental spelling system (http://www.youtube.com/watch?v=uunf3FDfEno).

### *B. Hybrid Mental Spelling System*

The hybrid mental spelling system was implemented by combining our previous mental speller with a web-camera (Part Number. 7795PC, Cosy Inc., Busan, Korea). The web-camera was attached at the center of the mental speller, and transmitted the eye direction information ('left' or 'right') to the operating computer in real-time. To estimate whether the user directed his/her eyes to the right or the left, the web-camera took 30 pictures of the user's eyes per second. The 2D coordinate was also extracted using in-house software developed by the authors.

The operating principles of the hybrid mental spelling system were identical to those of the previous one, except that a character identified by SSVEP was not typed if the eye-gaze direction estimated by the eye-tracker was not matched with the position of the selected character ('left' or 'right'). Fig. 2 shows the fabricated hybrid mental speller and two reference lines to determine whether a character decoded from SSVEP analysis belongs to the left or the right area of the keyboard. The two reference lines were selected considering the low spatial resolution of the web-camera. Please note that no calibration procedure was applied before using the web-cam eye-tracker.

### *C. Participants and Experimental Conditions*

Ten healthy participants (seven males and three females, 22-28 yrs old) participated in this study to evaluate the performance of our hybrid mental spelling system. All participants had normal or corrected to normal vision and none had a previous history of neurological, psychiatric or other severe diseases that might otherwise affect the experimental results. Before the experiment, we explained a detailed summary of the experimental procedures to each participant and received a written consent from all participants. After the experiment, we gave them monetary reimbursement for their participation. The study was reviewed and approved by the Institutional Review Board (IRB) of Hanyang University, Korea.

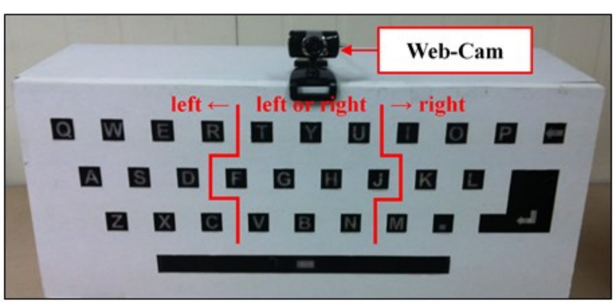


Fig. 2. The implemented hybrid mental keyboard and the reference lines to divide the mental speller into 'left' and 'right' areas.

The participants sat in a comfortable armchair in front of the hybrid mental speller, and the distance between the nasion of the participant and the hybrid mental speller was set to 44 cm (visual angle: 40°). According to the international 10-20 system, three electrodes (Oz, O1 and O2) were mounted on the occipital area of the participant's scalp. We used a multi-channel EEG acquisition system (WEEG- 32, Laxtha Inc., Daejeon, Korea) to record EEG signals while the participant was concentrating on target characters flickering at different frequencies. A reference electrode was placed at the right mastoid and a ground electrode was placed at the left mastoid. The EEG signals were sampled at 512 Hz. An anti-aliasing band pass filter with cutoff frequencies of 0.7 Hz and 50 Hz was applied before the sampling. In order to prevent misidentification of eye gaze direction due to head movement, the neck of the participant was fixed using a chin pad (see Fig. 3). As EEG signals were measured around the occipital lobe, they were almost free from eye movement artifacts. Thus, we did not apply any preprocessing methods to the recorded EEG signals.

### *D. Experimental Procedures*

To confirm the feasibility of the hybrid mental spelling system, a series of online experiments were conducted. After the participants had some training time to get accustomed to the hybrid spelling system, they were instructed to completely spell the given 15 English words (68 characters, see Table I). The time period required to spell one character was given to each participant differently (3-6 s). Since we used different time periods (3, 4, 5, and 6 s), proper numbers of zeros were added to the end of the EEG data to keep a frequency resolution to be 0.1Hz. The result was presented to the participants using both visual and auditory information in real time. In case of error, the participants should correct a misspelled character using the 'BACKSPACE' key. If the gaze direction information from the eye-tracker did not coincide with the position of the character decoded from SSVEP responses, a beep sound was presented. At that time, the participants were asked to just gaze at the target character again without any correction procedure. Fig. 3 shows a snap shot of the online experiment where a participant was trying to spell 'E' to spell a given English word, 'ZONE'.

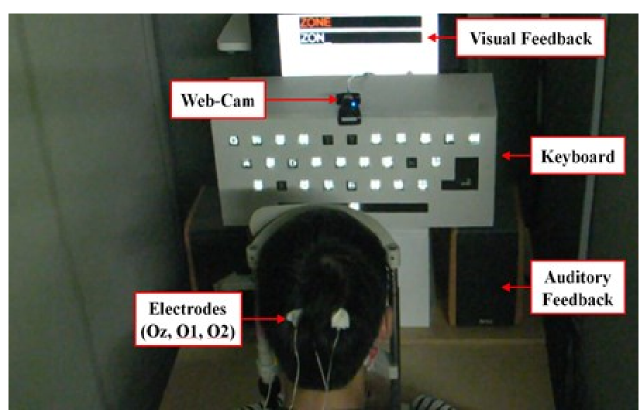


Fig. 3. A snapshot of the online experiments.

TABLE I. THE EXPERIMETNAL RESULTS OF A PARTICIPANT (P8). EACH CHARACTER IN ROUND BRACKETS MEANS TYPING ERRORS PREVENTED USING WEB-CAM EYE-TRACKER. THE 'BACKSPACE' AND 'SPACE' KEYS ARE DENOTED AS '←' AND '_', RESPECTIVELY.

| Target character | Typing results | Number of typing | Number of prevented errors |
|---|---|---|---|
| BABY | B (J) A B (X) Y | 6 | 2 |
| DESK | D (I) (N) (M) E (L) S K | 8 | 4 |
| GOLF | G (Z) O L (M) F | 6 | 2 |
| HAND | H A N T L ← F ← ← D | 10 | 0 |
| FACE | F A C (I) (I) (M) E | 7 | 3 |
| HOUR | H (Z) I ← O U R | 7 | 1 |
| TAXI | T (L) A X I | 5 | 1 |
| ZONE | Z O U (W) ← (ENTER) N (I) E | 9 | 3 |
| JUNE | P _ _ ← ← ← J U N (M) E | 11 | 1 |
| WATER | W A T (M) (M) E (L) R | 8 | 3 |
| WOMAN | W (Z) O M A N | 6 | 1 |
| VIDEO | V I D S (E) ← E M I ← ← O | 12 | 1 |
| QUICK | (L) (ENTER) (L) (ENTER) Q U I C K | 9 | 4 |
| PENCIL | V ← P E N C I L | 8 | 0 |
| MEMORY | M (I) (M) (M) (M) E (E) M O (L) R Y | 12 | 6 |
| **Total** | | **124** | **32** |

## III. RESULTS

(P8, a male subject who showed the worst performance) to demonstrate how the participant spelled the given 15 English words. The participant entered characters (including 'BACKSPACE' key) 124 times to completely type 68 characters. The total number of typos was 44, but 32 additional typing was prevented by using the eye-direction information extracted from the webcam-based eye tracker. That is to say, the participant would need to enter at least 32 characters more if the eye-tracker information were not taken into account. Since the time period required to spell one character was set to 4 s for P8, the participant could save 128 s (= 32 x 4 s) to spell the 68 characters.

TABLE II. THE RESULTS OF ALL ONLINE EXPERIMENTS

| participants | Time to gaze one character (s) | Number of total typed characters | Number of prevented errors |
|---|---|---|---|
| P1 | 3 | 101 | 21 |
| P2 | 6 | 123 | 17 |
| P3 | 6 | 106 | 18 |
| P4 | 6 | 91 | 9 |
| P5 | 6 | 92 | 11 |
| P6 | 4 | 85 | 11 |
| P7 | 5 | 109 | 18 |
| P8 | 4 | 124 | 32 |
| P9 | 5 | 97 | 16 |
| P10 | 4 | 98 | 13 |
| **Average** | | **102.6** | **16.6** |

Table II summarizes the online experimental results of all participants. Table II demonstrates that at least 16.6 additional typing could be prevented on average, compared to our previous mental speller. From the table, it was confirmed that the proposed hybrid mental spelling system could significantly reduce the total number of typing, by preventing typing errors in advance.

## IV. DISCUSSION

In this study, we developed a hybrid mental spelling system that utilized both EEG signals and eye direction information extracted from a webcam-based eye-tracker. Online experimental results showed that typing errors could be significantly reduced by preventing mistyping in advance, demonstrating the feasibility of the hybrid mental spelling system. It is expected that the proposed hybrid mental speller would be a useful communication option for patients who cannot control their eyes well enough to use eyeball mouse, but can move their eyes horizontally.


## ACKNOWLEDGMENT

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