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Control of an Internet Browser Using the P300 Event-Related Potential

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Abstract. We have developed an internet browser that functions in conjunction with a brain-computer interface, enabling world wide web access through real-time classification of the P300 event related potential. Standard page navigation tools, hyperlink selection and page scrolling are available through user selection of symbols presented on a separate screen. The system was tested in healthy subjects, although future work will consist of testing the system with patients with severe paralysis (Locked-in Syndrome) to further evaluate the usefulness of the system for those lacking voluntary movement or control.

Keywords: Assistive devices, brain-computer interface (BCI), electroencephalography (EEG), rehabilitation

1. Introduction

Brain-computer interfaces (BCI) have demonstrated their potential over the past two decades to help individuals with debilitating peripheral nervous system diseases [Kübler and Neumann, 2005]. Of non-invasive BCI techniques involving electroencephalographic (EEG) recordings, many have been successful in assisting patients with amyotrophic lateral sclerosis (ALS) – a neurodegenerative disease which may lead to complete motor paralysis and no curative treatment available – or other peripheral nervous diseases in communication [Kübler and Neumann, 2005; Birbaumer et al, 1999].

A P300-based spelling device, originally created by Farwell and Donchin in 1988 and improved by several lab groups since its inception [Farwell and Donchin, 1988; Sellers et al, 2006; Krusienski et al, 2007], has had considerable success in allowing these patients to communicate efficiently with others. The underlying principle of the P300-based spelling system is the "oddball paradigm", a term used to describe a specific event related potential (ERP) that follows presentation of rare stimuli amongst expected or predicted stimuli. This ERP typically occurs approximately 300 milliseconds after the presentation of an unexpected stimulus, thus allowing a stimulus to be discerned from others [McCarthy and Donchin, 1981; Duncan-Johnson and Donchin, 1982].

Using this principle, characters are presented to the user of the P300-based spelling device in a 6x6 matrix on a black screen. The characters are then highlighted in a random, flashing sequence by row and by column, respectively. Users are instructed to focus attention on only one character in the matrix, the "targeted character". This selective attention to one character is then evident due to the presence of the ERP 300 milliseconds after the character's corresponding row and column were highlighted. It is therefore possible to identify the targeted character; the character's location is at the intersection of the row and column numbers with the P300 ERP results [Donchin et al, 2000]. Noted successful methods of users for P300-based spelling devices include silently counting the number of times the attended character was randomly highlighted or silently affirming that it had been highlighted at the moment the flash occurred.

The P300-based spelling device allows the user communication via character selection and therefore enables him or her to type without a requirement for voluntary motion. Although P300-based technology is seen as a reliable method for communication, it has never been applied to enable the use of an internet browser. However, for individuals already accustomed to the P300-based spelling system, the transition to the internet could combine the familiarity of a system they can already operate with the freedom of the world wide web, opening many opportunities for those who are severely paralyzed.

Although other browsers have been created for control with slow cortical potentials (SCP) or μ rhythm [Karim et al, 2006; Moore, 2003], this is the first time a browser has been created for control with the P300 ERP. Advantages this presents are the ability to select from multiple options (as many as are included in the P300 matrix) in one selection sequence, instead of having to make multiple selections in sequence to choose a specific option. For example, an earlier web browser used a binary control signal [Bensch et al, 2007], which required up to 12 selections for a web page with 24 available links, using typical BCI classification accuracy. Theoretically, a browser with P300 control can enable selection from as many links as the P300 matrix includes (for a 6x6 matrix, 36), and selection of a link could be completed in one step.

For this reason we have extended development of a version of a "Neural Signal Surfing Interface" referred to as NESSI, an internet browser that uses EEG control for navigation. This version of Nessi uses P300 navigational control is an expansion of the ideas behind the original version of Nessi, which used SCP for control [Bensch et al, 2007]. The intended goal of Nessi is to provide a user-friendly and efficient tool for internet surfing.

2. Material and Methods

2.1. Apparatus

Hardware

An EEG 16-channel cap is connected to an amplifier and connected to a computer. We used a 16 channel gUSBamp (gtec, Graz, Austria) with a sampling frequency of 256 Hz (Highpass: 0.1 Hz, Lowpass: 60 Hz, Notchfilter: 50 Hz). The 16 Electrodes used are a subset of the international 10-20 system. Ground was placed on the left mastoid (A1) and reference on the right mastoid (A2). BCI2000 was used to present the stimuli and record the signals [Schalk et al, 2004].

Software

By adapting Mozilla's open-source browser, Firefox, and combining many other "add-on" software programs designed to enhance internet browsing experience. These add-ons can then be tailored to each user; here, the combination of the add-on software is tailored to function in conjunction with the P300-based spelling system. The following description of the Nessi system is based upon the functions of free and available add-ons and unique and original programming essential to incorporating BCI2000 software [Schalk et al, 2004;], upon which the P300-based spelling system operates (software available at http://www.bci2000.org).

2.2. Link Selection

Tag Presentation

In order to operate the Nessi browser, two screens must be presented to the user: one with an adapted traditional P300-based spelling matrix, and another screen available for presentation of the Nessi browser. When an internet page is loaded in the Nessi browser, the hyperlinks on the loaded page are internally listed in order of location on the page, starting from top to bottom and then left to right. All hyperlinks are then assigned a "tag", proceeding in alphabetical order, which denotes the order in which they appear on the page. This tag, consisting of one or two letters, is presented after a short, predefined delay to the user; it translucently hovers directly over the physical location of the hyperlink on the screen, allowing the user to read the text of the hyperlink and the tag itself (Fig. 1). In order to follow a hyperlink and advance to new web page, the "tag" code must be entered via the other user screen with the P300-based spelling matrix, hereafter referred to as the "Nessi matrix" (see

Section 2.6). An adjustable, predetermined time delay is enabled for the user to read over the current page and determine which hyperlink should be selected.

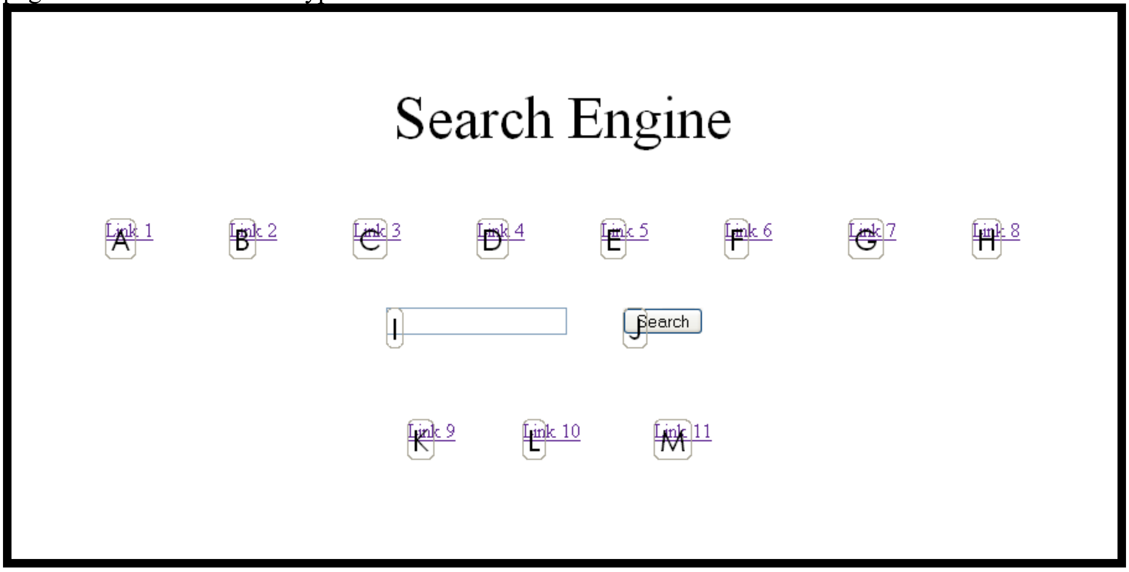

Figure 1. *The Nessi Browser screen during tag presentation. A letter corresponding to the P300 spelling matrix is assigned to each hyperlink, to indicate to the users which letter they have to chose from the matrix to select a hyperlink.*

Tag Selection

After the time delay, user attention shifts to the Nessi matrix screen. Unlike a standard 6x6 matrix, the Nessi matrix is an 8x8 matrix (Fig. 2), including letters, numbers, and a number of symbols which represent: standard browser navigational options, reading options, and typing functions for access to the browser's address bar, which are described in subsequent sections. The matrix screen then highlights the rows and columns in random order until each row and column has been highlighted once, for one complete sequence. Amount of repetition of sequences that is necessary is determined by a user's success using the P300-based spelling system, measured by the ability of this system to differentiate the P300 waveforms from others [Sellers and Donchin, 2006]. Users already accustomed to the system will likely need fewer repetitions of the random sequence to select the targeted character [Nijboer et al, under revision]. Another factor in determining the length of the sequence is variation of the latency and amplitude of the P300 response in individuals: the more variation the more repetitions are needed to discern the attended character.

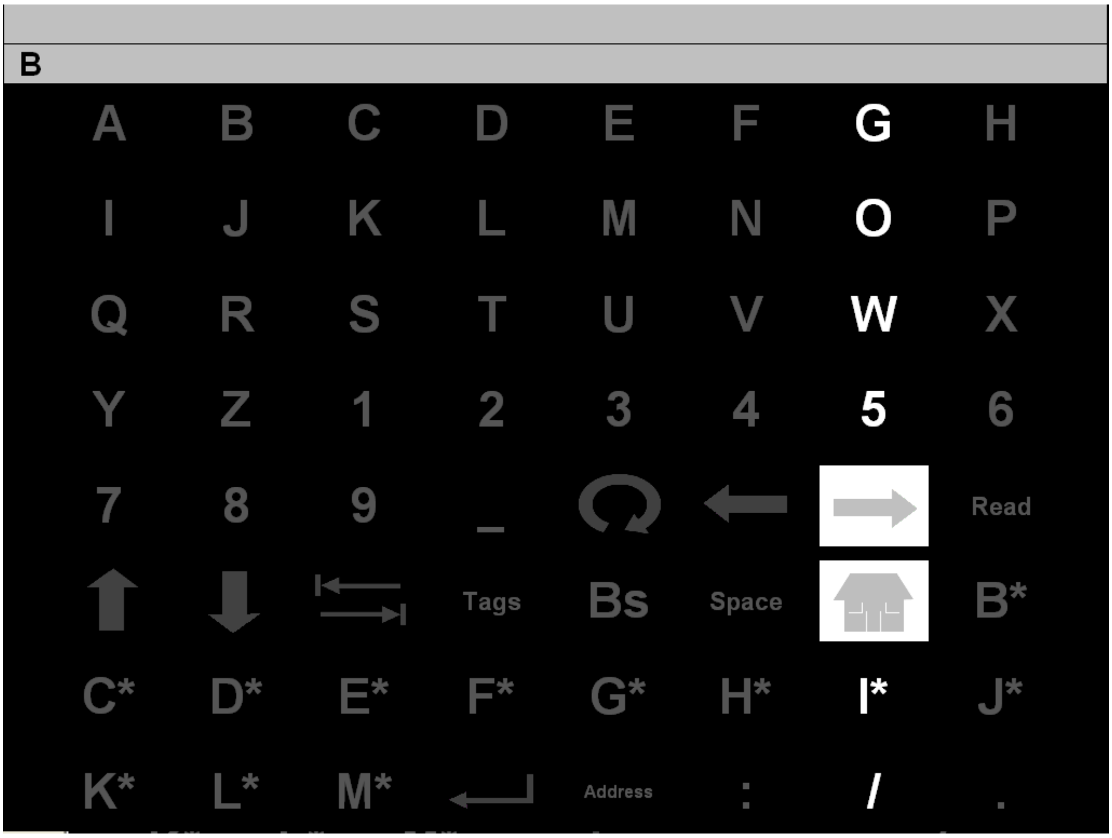

Figure 2. *The Nessi matrix screen, with all icons represented. Characters and symbols are highlighed in rows and in columns. Above, an example of a highlighted column; for icons, the colors invert. Also, feedback representing what is typed is shown; here, it is the letter "B".*

Once a character is selected, the command from the P300 matrix screen is presented to the user at the top of the screen to provide visual feedback, and the corresponding tag is first highlighted on the internet screen and then executed (i.e. the hyperlink's corresponding page is loaded) inside the Nessi browser (Fig. 3). Attention may then shift to the browser screen to continue with WWW browsing. Alternatively, should the selection be incorrect, the user may continue to focus on the Nessi matrix and seek to correct the error by focusing attention on "Bs" (short for backspace).

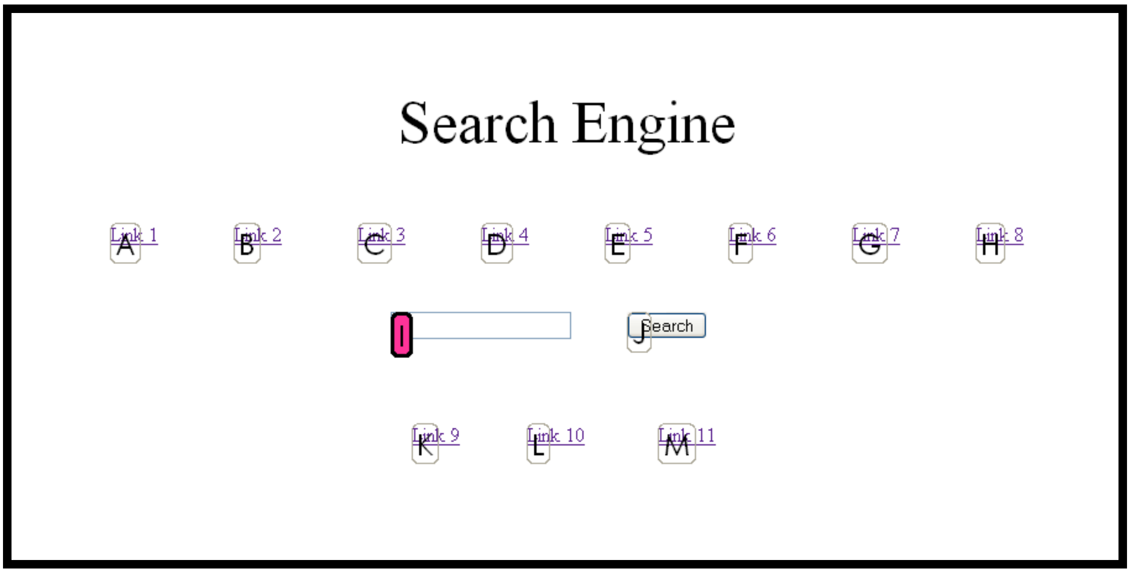

Figure 3. *The Nessi Browser screen after tag selection. Here, the selected link tag is "C".*

Star Character Options

Many pages on the internet include more than 26 hyperlinks on a page, therefore making it necessary to identify hyperlinks using tags with two letters. For this reason, tags must also be selected in two letter format. To select a link with a two-letter tag, the user must repeat the selection process to select both the first and second letter. With this efficient strategy, all links on the page can be selected in at least two of these selection periods; however, the speed of selection of the first 26 hyperlinks is not hindered and can still be accomplished in one selection period.

This two-character tag selection is accomplished via the "star character" options in the Nessi matrix. In order to select the hyperlink associated with the tag "BA", the user first selects "B*" and then "A", also from the 8x8 Nessi matrix. When "B*" is first selected, the "B" is highlighted on the Nessi browser screen, verifying the user's selection. If a star character were mistakenly selected, the user can eliminate this error by selecting the "reload" command, described in Section 2.3.

2.3. Reading Functions

Reading Without Browsing

For pages that have a large amount of text, the user may want to read this text without automatic forced page navigation, a default for the Nessi system. To allow for page viewing, users may select the "read" function, which then disables forced page navigation. The Nessi matrix continues to flash during the reading period. The reading function can only be inactivated when "Tags" is selected, thereby redisplaying the tags over the links in the Nessi browser.

Scrolling

A scrolling function exists to enable users to scroll up and down the page, which is particularly useful during page reading. By selecting the up or down arrows, the page will reload in a position that is equivalent to pressing the "page down" key, thereby enabling the links presented further down on a page the possibility of being selected. On pages where scrolling is not possible, the page is simply reloaded if one of the scrolling options is selected.

2.4. Navigation Functions

Forward and Back

Standard navigation functions, such as forward and backward, are notated in the Nessi matrix as arrows pointing to the right and left, respectively. The backward navigation function is extremely useful in the case of an error in navigation, and users are instructed to use this option in the case of inaccurate navigation.

Reload

The reload function simply reloads the page in the browser window. Like the standard reload command common in internet browsers, this option may also be selected if something on the page is loaded incorrectly, or to update a page which may have changed in a given amount of time. Denoted by an arrow seemingly pointed in a circle, it can also be utilized if a star character has been selected in error; by reloading the page, the browser "forgets" what command was just entered, and the user has a proverbial clean slate to work with in the new, reloaded browser window.

Home

Before a Nessi browsing session commences, a specific web page of the user's choosing can be designated as the "home page" in the browser. This is then the first page that loads when opening the Nessi browser. Also, by selecting the icon of a house in the Nessi matrix, the home function allows users to navigate to this preset web page. This is a standard function on most internet browsers, and eases selection of some sites that may be difficult to find or of a personal favorite page of the user.

Address Bar

A special feature of Nessi is the ability to type specific web sites into the address bar at the top of the screen. This option can be selected via the "Address" icon in the Nessi matrix. Users can then type - via letter selection from the matrix - the web address into the address bar and select "Enter" to execute it in the browser.

2.5. Typing Functions

Typing functions must also be available to the user, as it is integral to a browser's function. Typing capabilities inherently provides accessibility to e-mailing, form entry, chatting, forum participation, informational searches with the use of search engines, and much more. Simple character entry is therefore possible with the Nessi system, and additional typing functions, including "space", "backspace", "enter", "tab", colon, forward slash and period, all facilitate typing activity in the Nessi browser.

2.6. Additional Information on P300-based spelling methods

For a detailed description of letter selection in the P300 matrix, we refer the reader to any of the following papers: Sellers et al, 2006; Serby et al, 2005; Donchin et al, 2000.

3. Results

The software has worked successfully in the lab setting and tested with a healthy 22 year old female native-English speaker without P300-based spelling system experience. The tasks presented were to navigate through pages in Wikipedia to find pages of personal interest from the Wikipedia Main Page and to test all functions of the Nessi system during a 20 minute period of time. Free surfing was possible during this time period, using only the Nessi navigation functions and staying within the realm of Wikipedia. For this subject, the number of flashing sequences necessary for selection was (10 x 12 flashes) per trial. The interstimulus interval (ISI) was 125 ms (2 blocks) and presentation time 62.5 ms (1 block). Accuracy was reported directly by the subject as to what was the intended selection immediately after the selection took place; the user was able to achieve 90% accuracy during the 20 minute session. Page navigation through over 30 Wikipedia pages was possible during the 20 minute time period using just the P300 signal and the Nessi system. Verbal feedback from the user after the browsing session was positive, with suggestions as to the duration allotted for reading and typing into the search box. A sample waveform of the subject is presented in Figure 4.

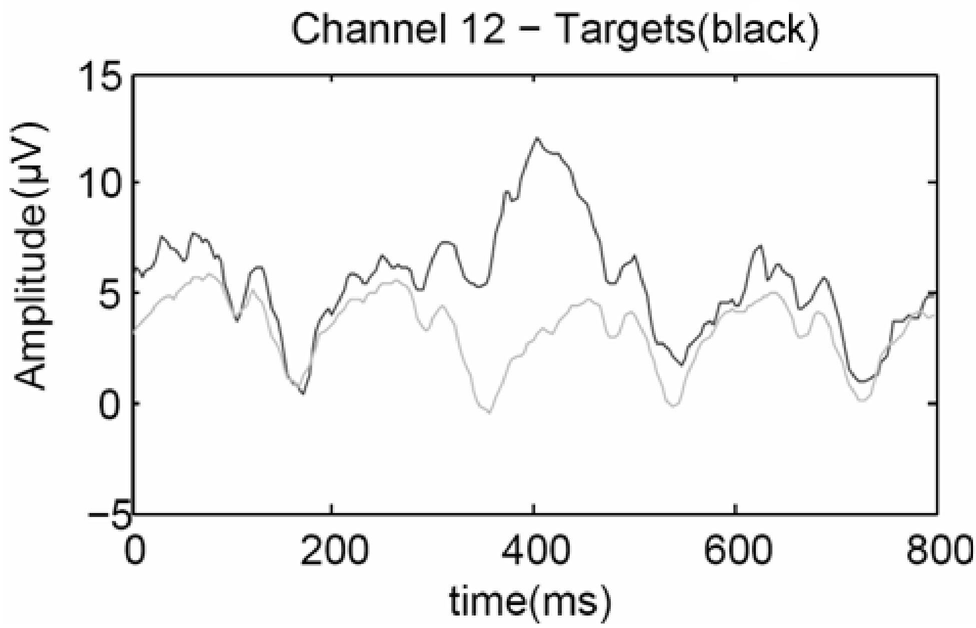

Figure 4. *A sample EEG waveform of the subject, taken from the Cz-position electrode and averaged over 10 trials. Amplitude of voltage potential (mV) is graphed versus time after stimulus presentation. Black line: averaged response to target icons in the P300 matrix; light grey line: averaged response to non-target trials*

4. Discussion

The Nessi internet browser system is efficient and easy to use, especially for individuals that have previously used P300-based spelling devices. Additionally, there is little to no adjustment time required for training users on a system using the P300 ERP, unlike those systems that use SCP control [Kübler et al, 2001].. We can therefore conclude that Nessi is superior to other brain-computer interface internet browsers [Karim et al, 2006; Moore, 2003; Bensch et al, 2007]. Its functions are easy to interpret, with icons and symbols based on traditional browser symbols and its logical display of alphabetized tags presented directly above each physical hyperlink.

It is believed that Nessi can operate with all web-based e-mail applications and various browser chat functions. Nessi has been proved to work with sites as diverse as eBay, Amazon, The New York Times Online, and Wikipedia. Other functions, such as user log-in pages, are also possible with Nessi.

A drawback to the Nessi browser system is its current requirement for two monitors to display the two screens. Most users do not have two monitors connected to one computer, and in order to increase the efficacy of the system, the two-screen display should be condensed into a two window display on one screen. This would also further assist individuals with severe motor paralysis; intact eye movement or potentially some head movement – which may be impaired in such patients - is required if attention must switch between two monitors.

In future work, Nessi will be tested for speed in comparison with other models on a wide variety of assorted web pages; however, Nessi will also be tested and qualitatively evaluated with individuals with ALS.

With 10 sequences for item selection and a peak amplitude latency of approximately 400 ms after stimulus presentation the P300 of the user was in the normal range. This indicates that the additional work load imposed by processing a web page and identifying the tag assigned to the desired link did not affect classification of the event-related potential.

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Appendix

Interested readers can find software at http://nessi.mozdev.org .

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