Communication in locked-in state after brainstem stroke: a brain-computer-interface approach

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In a recent study by Sellers *et al.* (1) a patient in locked-in state after brainstem stroke was able to successfully communicate via electroencephalography (EEG) based brain computer interface (BCI) employing a P300 speller paradigm.

BCI uses the brain signal, which can either be the electrical signal (electroencephalography-EEG) (2) or a change in hemodynamic activity [functional magnetic resonance imaging-fMRI (3,4; near infrared spectroscopy-NIRS (5)], to enable patients lacking control of their muscles in communication and controlling external mechanical devices. BCIs using EEG exist since 1970's (6) and several researchers have developed BCI using different features of EEG, namely slow cortical potential (SCP) based BCI (7,8), sensorimotor rhythm (SMR) based BCI (9,10) and P300 based BCI (11,12). The scientific literature is full of BCI studies done on healthy human participants where the participants' moved an object on the computer screen (9), wrote a sentence (8) and moved a robotic arm (13) among several other tasks. Limited studies have been performed on patient populations where the BCI can improve lost functions of individuals with disabilities. In that light it is very exciting whenever a BCI study is performed on an individual who is in dire need of such a technology. In our laboratory SCP-BCI (7,8,14), SMR-BCI (10,14) and P300 BCI (14) have been used extensively since 1999 to help ALS patients in locked-in state in communication. To date very limited research has been done on the application of BCI for communication in patients in locked-in state (LIS) after brainstem stroke. In the scientific literature there are two different studies describing the application of BCI in patient in LIS after brainstem stroke (15,16). In one of the

study the patient in LIS after brainstem stroke was trained to control her SCP but the study could not be carried on further as the patient regained some muscular control to some extent (15). In the other study P300 based BCI was used to train a patient in LIS after brainstem stoke, to move a ball on the screen towards a specified target (16). To date no study has been published prior to Sellers *et al.* (1) were BCI was used for communication in a patient in LIS after brainstem stroke.

In the recent study (1) a P300 speller based BCI was used for communication in a 68 year old male who suffered a multifocal acute ischemic infarction and had little control over eye blinking. If the patients have stable control over their eye blinking or if they can fixate their gaze, eye assistive technology can be used for communication. In the present study the participant attempted unsuccessfully to communicate with a MyTobii eye-tracking device for 2 months. The participant tried to move his eyes up to answer the "yes" and down to answer the "no" questions, but the response was variable. This is generally the case in ALS patients in transition from LIS to completely locked-in state (CLIS), wherein the patients ultimately loose eye control (17). Since brainstem stroke is not a progressive neurodegenerative disorder the patient may never suffer the transition from LIS to CLIS. Hence a visual BCI called P300 speller can be used successfully for communication in these kinds of patients because vision is intact, which is often not the case in ALS locked in patients. The P300 speller is based on an oddball paradigm where an event related potential (ERP) is elicited over the parietal cortex, 300 ms post the attendance of rare stimuli by the participant. In the classic P300-BCI, first introduced by Farwell and Donchin,

participants are presented with a 6×6 matrix where each of the 36 cells contains a letter or a symbol (Farwell and Donchin, 1988) (11). This design becomes an oddball paradigm by first intensifying each row and column for 100 ms in random order and then, by instructing participants to attend to only one (the desired) of the 36 cells. Thus, in one trial of 12 flashes (6 rows and 6 columns), the target cell will flash only twice constituting a rare event, compared to the 10 flashes of all other rows and columns and will therefore elicit a P300 (Sellers and Donchin, 2006) (12). The same oddball paradigm can be used to design different kind of speller consisting either all the alphabets and numbers, as in classical speller design, or certain known words like "yes", "no", etc. In the reported study Sellers *et al*. (1) employed seven different types of spellers, based on oddball paradigm described above, to ascertain the efficacy and speed of communication in patient in LIS after brainstem stroke.

In the reported BCI study, which was initiated 6 months after the stroke and discharge of participant from the nursing home, Sellers *et al*. (1) employed the speller both in copy spelling and free spelling mode in a total of 62 sessions during 34 separate visits spread across 56 weeks. The copy spelling mode, during which the participant was instructed to attend a specific character, was used as the BCI calibration procedure. If initial accuracy was greater than 70%, during the copy spelling mode, i.e., the calibration, the participant switched to free spelling mode without further calibration (expect two sessions where the BCI accuracy during calibration was relaxed to 62 and 58%). The study started with the employment of standard 6×6 speller across seven session out of which only 2 sessions yielded accuracy greater than 70% with a mean accuracy of 32.3% in copy spelling mode. On the basis of these results Sellers *et al*. further tested several different paradigms. First they used a four-choice P300 BCI task with choices namely: yes (Y), no (N), pass (p) and end (E) across seven sessions. The participant was asked to focus on an appropriate choice, to answer the question, as each option was flashed randomly. The four-choice BCI yielded accuracy greater than 70% across all the seven sessions with an average mean accuracy of 94.7%. Although the accuracy across all the seven sessions were greater than 70%, the four-choice BCI has an inherent limitation where the response of the participant is limited to only four choices and the participant does not have the ability to express his/her wishes directly. Keeping in this mind and building on the success of the four-choice BCI Sellers *et al*. designed a seven-choice toggle display. In this

design the English alphabet was divided in 5 groups: namely A-E, F-J, K-O, P-T, U-Y, two additional options of selecting the backspace and going back to main menu were provided on each screen. if the participant selects a group K-O an another screen picture would appear where the participant can select any letter between K to O, along with an option of using backspace to correct the selection and going back to main menu. The seven-choice BCI was used across four sessions where in the accuracy across all the four sessions was greater than 70% and it yielded a mean accuracy of 85.6%.The main limitation of the seven-choice design was the need to navigate across six sub-menus to perform several selections. So to further extend the efficiency and speed of selection Sellers *et al*. designed a larger display with one sub-menu: namely 3×5 and 3×6 display. The 3×5 speller could not be used for more than session because it did not provide the necessary items to compose sentences with only one sub-menu. The 3×6 speller speller provided more selections than the 3×5 speller and had all the necessary items to compose a full sentence with only one sub-menu. Thus Sellers *et al*. extensively used the 3×6 speller for communication in participant in Locked-in state after brainstem stroke. The 3×6 speller was employed for a total of 19 sessions and the accuracy was greater than 70% for 11 sessions with a mean accuracy of 81.5%. Sellers *et al*. then shows different messages the participant was able to communicate using the 3×6 speller, wherein he expressed his desires to buy present for his wife and jacket for his sons among others. They then also compared the speed and accuracy of 3×6 speller with the letter board and they report that the 3×6 speller took 24 min with correct selection every 1.33 min to complete a particular sentence in comparison to 29 min taken by a letter board with correct selection every 3.22 min.

In summary in the reported study (1) Sellers *et al*. demonstrated successful communication via a noninvasive BCI in a patient in LIS after brainstem stroke. The BCI provided a level of autonomy and a sense of independence to the participant by completely bypassing his otherwise non-functional muscular control. Thus, these results strengthen the long standing assertions in the BCI field on the successful BCI use of a visual, noninvasive P300 speller in a patient in LIS after brainstem stroke thereby raising hope that the BCI can be useful to those with LIS in patients with brainstem stroke too after the successful demonstration of brain- communication in a completely locked-in patient with amyotrophic lateral sclerosis (ALS; Gallegos-Ayala *et al*. 2014) (18). This study (18) and the

Sellers *et al.* (1) study underscore the tremendous potential of non-invasive BCIs to cope with the unbearable condition of complete isolation from the social environment. More studies like this is needed to reliably establish the applicability of BCI for communication in LIS and particularly in CLIS (completely locked in patients without eye-control) patients.

Acknowledgements

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