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Editorial

# Toward a gaze-independent matrix speller brain–computer interface

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Many people affected by debilitating neuromuscular disorders such as amyotrophic lateral sclerosis (ALS), brainstem stroke, or spinal cord injury are impaired in their ability to communicate. Conventional assistive devices (e.g., letter boards, cheek or tongue switches, or eye trackers) that aim to restore communication all require muscular control, which is often lost in the progress of neuromuscular disorders.

A brain–computer interface (BCI) uses brain signals directly, rather than muscles, to re-establish communication with the outside world. One well-known BCI approach is the so-called "P300 matrix speller" that was first described by Farwell and Donchin (1988). In this system, the user pays attention to a character in a matrix while each row and column is intensified rapidly and randomly. The brain produces a response to the row or column that contains the intended character (i.e., the oddball); this response is not present for the other rows or columns. The BCI typically averages several responses, detects the row and column with the strongest responses, and thereby identifies the character the user wants to select.

The individual parameters of the matrix speller have each been studied and optimized extensively. This includes the matrix size (Allison and Pineda, 2003), stimulation frequency (Sellers et al., 2006a), stimulation intensity (Takano et al., 2009), classification algorithm (Krusienski et al., 2006), and electrode locations (Krusienski et al., 2008). The matrix speller approach has been used in several application contexts, such as web browser navigation (Mugler et al., 2008), control of ambient environment (Edlinger et al., 2009), wheelchair navigation (Rebsamen et al., 2007), and mouse movement (Citi et al., 2008). Moreover, it has recently been shown that more than 80% of the healthy population can use such a BCI (Guger et al., 2009), which demonstrates the broad applicability of this approach in people without disabilities.

Most important to the eventual goal of BCI research, there is mounting evidence that the matrix speller can also restore function in severely disabled individuals (Piccione et al., 2006; Sellers et al., 2006b, 2010; Vaughan et al., 2006; Nijboer et al., 2008; Kübler and Birbaumer, 2008; Silvoni et al., 2009; Hoffmann et al., 2008; see Donchin and Arbel, 2009 or Mak and Wolpaw, 2009 for comprehensive reviews). However, these studies typically report spelling performance that is lower than that reported in similar studies using healthy individuals.

This decreased spelling performance in patients compared to healthy individuals may be related in part to cognitive impairment (Phukan et al., 2007) or to the inability to maintain gaze. For example, eye gaze is often impaired or lost in subjects affected by ALS. Although some people with ALS maintain residual eye movement for years (Cohen and Caroscio, 1983; Palmowski et al., 1995; Birbaumer and Cohen, 2007), others progress to near-complete or complete paralysis. This is problematic, because recent studies (Brunner et al., 2010; Treder and Blankertz, 2010) showed that the traditional design of the matrix speller not only relies on the P300 evoked potential, which does not depend on eye gaze, but also on other features such as visual evoked potentials, which strongly depend on foveation and thus the ability to control eye gaze direction. This recent finding has contradicted the widespread assumption that the performance of the matrix speller does not depend on the subject's ability to fixate on the target character (Donchin et al., 2000; Serby et al., 2005; Sellers et al., 2006b). In addition to the dependence on eye gaze, the spelling rate supported by the matrix speller BCI is still an order of magnitude lower than what conventional assistive devices can provide (Majaranta and Räihä, 2002; Schalk, 2008). In sum, the limited speed and dependence on gaze of the traditional design of the matrix speller BCI limits the practical value of this BCI approach to individuals in the target population.

Recent studies have attempted to address these two issues. To improve spelling performance, studies have optimized stimulus presentation and algorithms to detect the intended letter. For example, recent studies employed faster stimulation (McFarland et al., 2011), more robust coding (Hill et al., 2009; Townsend et al., 2010), or probabilistic measures of the letter frequency (Martens et al., 2010). However, these approaches have only modestly increased or in some case even decreased spelling performance. It is likely that the limited gains of these approaches is due to physiological constraints of the brain. For example, limited speed of cortical processing will define the maximal stimulation frequency.

To remove or mitigate the dependence of the matrix speller on eye-gaze, recent studies used oddball paradigms with auditory (Klobassa et al., 2009; Kübler et al., 2009; Schreuder et al., 2010), tactile (Brouwer and van Erp, 2010), or simplified visual stimuli (Treder and Blankertz, 2010).

In the latter study, the selections were arranged within the peripheral visual field in a circle rather than a matrix. In this approach, the selection was performed using a two-stage process, i.e., initial selection of a group of characters followed by the selection of the intended character. This study showed in healthy individuals with constrained eye gaze that spelling accuracy using the traditional row/column speller was 40%, but that this accuracy improved to 60% with the circular approach. While this result is encouraging, further improvements to accuracy in this gaze-independent approach were needed.

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In their study, in this issue, Liu et al. (2011) used a one-stage selection scheme that arranged the stimuli (i.e., only the characters of intensified rows or columns of a matrix rather than all characters of that matrix) in a circular fashion. This circle of characters was presented around the center of a computer screen, and the subjects were asked to fixate gaze on the center of the circle. In contrast to the traditional matrix speller, in which characters were always presented at the same position (which subjects can memorize), in this paradigm, the subjects needed to search for the target character, which limits the speed at which the characters can be presented. In other words, the only change relative to the conventional matrix speller was the visual presentation of the $6 \times 6$ matrix. This study in eight healthy subjects reported an average accuracy greater than 90% (2.6% chance) at a rate of about one character per minute. In summary, this study combined high spelling accuracy with gaze independence. With additional verification in people with paralysis and limited gaze, this approach may lead to an accurate spelling solution for this population. In conclusion, this study further encourages exploration of the value of this and similar BCI approaches to people with severe neuromuscular disorders.

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