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Novel Paradigms for Auditory ERP Spellers with Spatial Hearing: Two Online Studies

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Abstract. Two separate online studies with healthy subjects investigate the usability and the speed of novel Brain-Computer Interface paradigms that exclusively use spatial-auditory stimuli to drive an ERP speller. It was found that participants could use both paradigms (named AMUSE and PASS2D) for a spelling task with an average accuracy of over 85% and high speed (~0.9char/min). Based on these results, the paradigms qualify for future studies with patients, that suffer from a loss of gaze control.

Keywords: Brain-Computer Interface, auditory ERP, Spatial Auditory Stimuli, Spelling Application

1. Introduction

Using Brain-Computer Interfaces (BCI) one can establish a communication pathway which does not rely on muscular activity. This is a promising tool for patients suffering from neurodegenerative diseases like amyotrophic lateral sclerosis (ALS). Since visual BCI paradigms might not be eligible for those patients [Treder and Blankertz, 2010], auditory paradigms were recently investigated [Schreuder et al., 2010; Nijboer et al., 2008; Kanoh et al., 2008]. Spatial hearing has been introduced as informative cue in a BCI paradigm [Schreuder et al., 2010], revealing that subjects are able to focus attention to a target direction. The present work investigates the usability of speller paradigms with spatial auditory cues based on two online studies.

2. Material and Methods

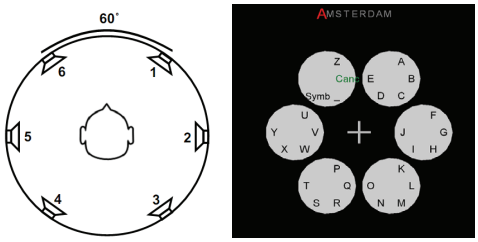

Figure 1*. Experimental setup (left) and spelling procedure (right) in the AMUSE paradigm.*

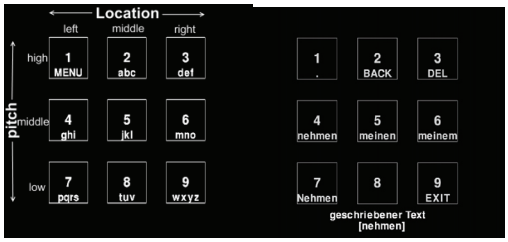

Figure 2. *Visualization of the auditory PASS2D paradigm: spelling mode(left), selection mode (right).*

2.1. AMUSE paradigm

The AMUSE paradigm (standing for Auditory MUlticlass Spatial ERP), as presented in [Schreuder et al., 2010], was adapted for online text writing. It consists of a ring with 6 audio speakers around the subject (Figure 1a) which produces stimuli in a pseudo random order. The inter stimulus onset interval (ISOI) was 175ms with each tone lasting 40ms. 21 naive, healthy subjects, who gave informed consent, participated in an online experiment with two sessions with the final task to spell a pangram. In the second session, an early stopping method was applied to further increase the spelling speed.

An adapted version of the hex-o-spell speller [Blankertz et al., 2006] was created in which characters can be selected in a two step process, see Figure 1. First, a group of letters is selected (example: A-E) by focusing on the corresponding direction. In the second step, the characters are divided over five of the directions and an individual letter can be selected. Choosing the sixth direction returns the user back to the first selection step.

2.2. PASS2D paradigm

As a second paradigm, a two-dimensional auditory speller paradigm was investigated: stimuli varied in pitch (high/medium/low) and location (left/middle/right). The resulting nine stimuli were presented using standard headphones. As an example, stimulus '4' was a tone with medium pitch, presented on the left channel (Fig. 2). ISOI was 225ms with each tone lasting 100ms. The paradigm is called PASS2D standing for Predictive Auditory Spatial Speller with two-dimensional cues.
12 healthy subjects, who gave informed consent, participated in an online experiment with one session and the final task to spell two sentences (16 and 36 characters). None of the subjects participated in the study of the AMUSE paradigm.
A novel spelling system is investigated: instead of selecting letters from a matrix or a group-wise representation, letters and words are spelled with a predictive text system, which is very similar to the T9 system on mobile phones. Using this system, one is able to spell a character with a 1 out of 9 selection (Fig. 2). The system was set up with a German dictionary of about 10,000 frequently used words in the German language. For interaction, two different modes were implemented, see Fig. 2.

3. Results

With the AMUSE paradigm 16 out of 21 subjects were able to spell with an average spelling speed of 0.592 characters/minute in the first session. In the second session, 14 out of those 16 subjects were successfully spelling with an average speed of 0.92 characters /minute. The average multiclass accuracy in both sessions was 85%.
Using the PASS2D paradigm, ten out of twelve subjects were able to spell a text with a mean selection accuracy of ~90% and an averaged spelling speed of 0.81 characters /minute.

4. Discussion

The usability of two speller paradigms with spatial-auditory cues (named AMUSE and PASS2D) was investigated in separate online experiments. Class-discriminative N200 and P300 components were found in both studies, revealing that participants were capable to attend to two-dimensional auditory cues. Compared to visual paradigms, the performance (assessed to be below 1 char/min for both paradigms) is relatively low. However, as PASS2D and AMUSE can be used strictly auditorily, they may better serve the need of late-stage ALS patients with vision deterioration. Those results show that both paradigms are fast and accurate enough to be possibly used as a communication channel for patients that are unable to use visual spellers.

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