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Motor Imagery BCI Feedback Presented as a 3D VBAP Auditory Asteroids Game

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Abstract. Typically, a brain-computer interface (BCI) relies upon visual feedback which is impractical for those with vision problems, whilst long term use of the system can often become tedious. This study demonstrates the feasibility of using 3D vector base amplitude panning (VBAP) as a technique for presenting auditory feedback in the form of an asteroids avoidance game. Seven healthy participants were presented with both visual then auditory feedback for comparison. Auditory feedback was presented using 1, 2, or 8 loudspeakers. Results show no difference in performance with some subjects scoring markedly better than others.

Keywords: Sensorimotor rhythms (SMR), brain-computer interface (BCI), audio feedback, games, vector base amplitude panning (VBAP)

1. Introduction

Motor imagery (MI) brain-computer interfaces (BCIs) typically present feedback visually which relies upon the vision of the user remaining intact. However, amyotrophic lateral sclerosis sufferers have shown to exhibit ocular instabilities even from the early stage of the disease [Balaratnam et al., 2010]. Similarly, those in minimally conscious or vegetative states may also benefit from feedback methods which do not depend on the visual channels [Coyle et al., 2012]. It may be possible to improve the performance of a BCI by exploiting our inherent ability to localise an auditory event in the free field by adjusting its relative position and hence provide feedback of sensorimotor rhythms (SMR). Our findings show that results are comparable to other feedback modalities hence it is expected that the system will be more appealing to use over longer periods.

2. Material and Methods

Mu and beta rhythm EEG (8-13 Hz) was recorded from 7 healthy participants (6 male, mean ages 26 years ± 6.3, 2 naive) using 3 bipolar channels (C3, Cz, C4, FPz ref.) sampled at 125 Hz. Pre-processing was carried out using a 'neural time-series prediction pre-processing' model which uses self-organising fuzzy neural networks with common spatial patterns to maximize signal separability [Coyle, 2009]. XNA (Microsoft) was used to provide timings and visuals for both groups whilst Max/MSP (Cycling '74) provided auditory feedback. M-Audio AV20 powered speakers produced audio through a low latency audio interface (MOTU Ultralite Mk3). Sessions contained 240 trials (trial = 8 s) (Fig. 1) with audio and visual sessions interleaved. Visual training and feedback followed the classic arrow-ball/basket paradigm (Fig. 1a,b). Run 1 was used to train parameters, run 2 presented feedback whilst run 3 presented an asteroid avoidance game [Coyle et al., 2011]. Each auditory session contained 4 runs (run 1 for training) and mimicked the visual session in timing (Fig. 1). Auditory training presented spoken commands from left or right. One of three types of auditory feedback: single speaker (mono), dual speaker (stereo) or multiple speakers (VBAP) was presented, based on our previous work [McCreadie et al., 2013].

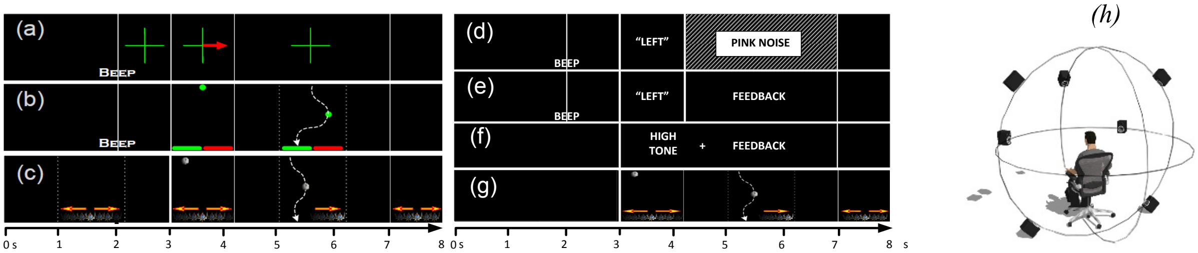

Figure 1. *(a) Visual training with no feedback (b) visual ball and basket (c) visual space ship game (d) audio training (e) stereo audio feedback (f) mono audio feedback (g) audio VBAP space game (h)VBAP speaker layout.*

Mono: The left target was indicated by a sawtooth wave at 196 Hz whilst right was assigned 1661 Hz. Feedback was given by a resonant filtered pink noise (196-1661 Hz) based on the time varying signed distance (TSD) classifier output which was perceived by the listener as an increasing and decreasing pitch to indicate correct MI.

Stereo: Speakers positioned at ±90°θ presented the target as a spoken command (“left”/“right”) from the corresponding loudspeaker. Output from the classifier or TSD was indicated by continually varying the azimuthal position of pink noise between ±90°. The addition of the broadband noise ensured that adequate spectral information was contained both above and below 1.5 kHz.

VBAP: Similar to the visual game, an auditory equivalent was delivered using VBAP. Speakers were positioned at: 90°θ 50°ϕ, -90°θ -32°ϕ, -45°θ 0°ϕ, 0°θ 50°ϕ, 0°θ -32°ϕ, 45°θ 0°ϕ, 90°θ 50°ϕ, 90°θ -32°ϕ (Fig. 1 (h)). The listener assumed control of a virtual auditory spacecraft similar to the visual session. The asteroid appeared from above and fell towards the ground over time with a beacon sound reinforcing the target direction, the aim being to avoid a collision and MI causing the spacecraft to move left or right. The sound of the asteroid was represented as a pink noise mixed with a tone which swept in frequency from 1.5 kHz to 150 Hz then summed (to simulate a falling sound) before passing through a tremolo effect set to an inverse sawtooth (freq.7.5 Hz). The target was indicated by a beacon sound (1 kHz sine wave) which occurs at either 90°θ, 0°ϕ or -90°θ, 0°ϕ combined with pink noise pulsed at 4 Hz. Each pulse lasted 30 ms with a fade-in and fade-out time of 5 ms.

3. Results and Discussion

Results are presented as the offline mean classification accuracy (mCA) from a 5-fold CV performed on individual runs, each run consisting of 60 trials (30 left, 30 right). Table 1 shows results from each subject obtained from every type of run. Whereas some subjects clearly perform better than others, all participants perform well overall with only two scores below 70%.

Table 1. *Subject classification accuracy means for each run.*

	Visual				Auditory				
Subject	Run1	Run2	Game	Mean	Mono	Stereo	VBAP	Mean	Mean
A	74.33	73.00	72.40	**73.24**	71.33	72.50	71.00	**71.61**	**72.43**
B	68.83	76.67	74.20	**73.23**	76.60	79.07	78.20	**77.96**	**75.59**
C	74.67	73.80	73.67	**74.05**	72.67	72.00	69.59	**71.42**	**72.73**
D	83.67	81.03	83.00	**82.57**	81.67	82.17	82.10	**81.98**	**82.27**
E	76.27	73.47	73.73	**74.49**	73.20	79.43	80.00	**77.54**	**76.02**
F	78.13	76.47	80.53	**78.38**	76.47	70.34	71.13	**72.65**	**75.51**
G	72.73	75.60	72.75	**73.69**	74.63	73.43	73.25	**73.77**	**73.73**

Mean classification accuracy results were calculated for each group and for every session. A t-test revealed no significant difference in performance between groups with the auditory group showing greater improvement. An ANOVA revealed no significant difference between the CA of any of the runs.

All subjects performed above the criterion of 70% although some outperformed others by the end of the experiment. Whilst no difference in performance between groups was observed, the auditory group showed the greatest improvement over time. Auditory feedback offers the visually impaired an alternative method of BCI control and freeing up the visual pathway may be advantageous for the visually able who need not focus on visual feedback. The development of a spatial auditory VBAP BCI paradigm creates a path to further advancement for more innovative multidimensional games which it is expected will go a long way to alleviating the tedium often experienced in longer training sessions.

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