Visual and Stereo Audio Sensorimotor Rhythm Feedback in the Minimally Conscious State

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Abstract. Previously we assessed awareness in a participant, diagnosed minimally conscious (MC), using an EEG-based sensorimotor rhythm (SMR) brain-computer interface (BCI). Here we describe a follow up study conducted over 2 intensive training phases, involving visual feedback and stereo auditory feedback (pink noise and music samples). The participant performed significantly above chance on most runs. Although both feedback modalities produce similar performance, auditory feedback is most suitable for this participant due the uncertainty of the participant's ability to follow visual cues and feedback. Stereo musical feedback is demonstrated for the first time.

Keywords: Minimal Conscious State (MCS), EEG, Motor Imagery, Auditory Feedback, Brain-computer Interface

1. Introduction

Those in the minimally conscious state (MCS) or vegetative state (VS) are often incapable of providing any overt motor responses however there is evidence that a subset of patients with these disorders of consciousness (DoC) can alter their brain activity in response to instructions. Cruse et al 2011 detected significant sensorimotor rhythm (SMR) activations in 19% participants in MC and V states, demonstrating that a subset were capable of sustained attention, response selection, working memory and language comprehension. We showed that real time SMR feedback during assessment of a patient diagnosed MC (Coma Recovery Scale-Revised score (4/23)) could impact on the awareness detection protocol, even though the patient had not communicated for 12 years [Coyle et al 2012]. Here we describe follow-up experiments to determine if the participant can learn to control a SMR-BCI.

SMR-BCIs enable the user to learn how to intentionally modulate their EEG through sensorimotor learning. Visual feedback in this closed loop system excludes those with visual problems. Those in MC/V states often have no/very limited gaze control/visual acuity. It is possible to substitute visual feedback for its auditory equivalent [McCreadie et al., 2013]. We provide the first results comparing visual and auditory SMR feedback in the MC state.

2. Material and Methods

One male participant (aged 28) who contracted juvenile posterior Fossa Astrocytoma in 2001 and, following significant surgery, was diagnosed MC requiring full assistance for all activities of daily living. Informed assent was given by the participant's family/medical teams. Ethical approval was granted by the National Rehabilitation Hospital Ethics Committees. The study was conducted in the participant's home. Phase 1 (visual cues/feedback/verbal prompts) took place approximately 6 months after initial assessment [Coyle et al., 2012]. Phase 2 (stereo auditory feedback) occurred 6 months later. Seven sessions involving 2-4 runs (60 trials/run), circa 1.5 hrs durations, 1-2 per day (morning/evening) were conducted in each phase. In phase 1, 3 bipolar EEG channels were recorded as in [Coyle et al 2012]. In phase 2, 16 channels over sensorimotor areas were recorded using a g.BSamp (www.gtec.at), digitized using a cDAQ 9171 (www.ni.com), oversampled at 2 kHz and average downsampled to 125 Hz. Only results from 3 Laplacian channels around C3, Cz and C4 are reported.

Stereo auditory feedback was given in two forms: as a broadband ($1/f$ or pink) noise, and for the first time music. The broadband noise, commonly used in auditory localization experiments contains cues both above and below 1.5 kHz, essential in the effective localization of an auditory event. A 'musical palette' was comprised of 10 different popular musical genres (e.g., blues, classical etc.). Each style contained three excerpts from tracks from each of three artists. Auditory feedback was presented through a set of ER4P earphones (Etymotic Research, Inc.). The earphones presented the target as a spoken command ("left" or "right") from the corresponding ear. Feedback was modulated by continually varying the azimuthal position of the sounds between ± 90° using left and right hand movement imagination. Visual feedback was given in the form of the standard ball-basket paradigm and an asteroids avoidance game in which the objective is to move a falling ball to one of two baskets on the left or right of the screen or move a spaceship to dodge asteroids which fall towards the spaceship either on the left or right of the screen, respectively [Coyle et al., 2011]. For both feedback paradigms the participant was given verbal instruction on how to control the feedback, during visual feedback periodically the participant was verbally prompted with the correct motor imagery (MI) to perform and to ensure awareness of target during periods of eye shutting/suspected visual acuity degradation. Trial timing was standard with cue at 3 s, feedback between 4-7 s for all feedback types.

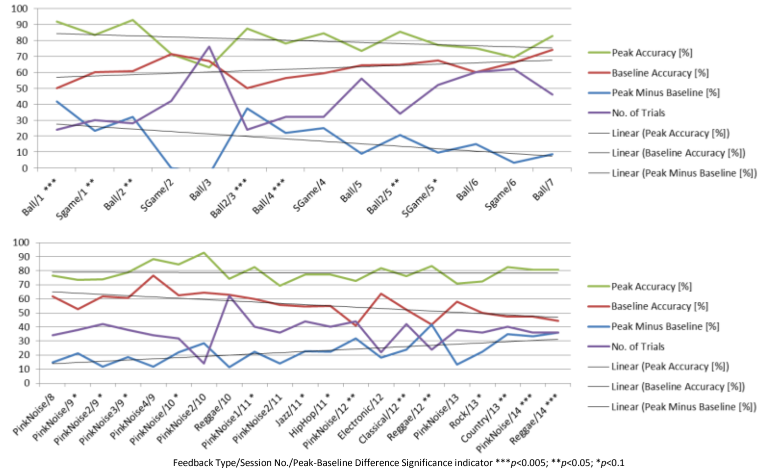

Figure 1. *Visual (top) and auditory (bottom) results. Peak , baseline (500 ms before cue) baseline-peak mCA from LOO-CV and no. of trials in each run after artefact rejection.Visual (top) and auditory bottom results showing peak mean classification accuracy from leave one out cross validation, baseline accuracy (500ms before cue), the difference between baseline and peak, and the number of trials*

The first run in each session used the classifier from the previous day for feedback or was a calibration run (no feedback). The classifier was updated on the data from the first run. Subsequent runs involved either type of visual feedback or pink noise followed by musical feedback (feedback runs reported only). As different runs involved different feedback types and, in the MC condition, awareness is unknown and can vary significantly, analysis is performed run-by-run. Due to the head strap occasionally distorting the electrode cap and/or the participant wheezing and/or teeth grinding it was necessary to reject a substantial number of trials (no. of trials per run are reported). A leave-one-out cross-validation (LOO-CV) was performed on each run using the BCI outlined in [Coyle et al., 2011]. Mean classification accuracy (mCA) is reported along with baseline accuracy (500 ms before cue).

3. Results and Discussion

Fig. 1 shows that there were consistent SMR activations during both phases with the majority of runs showing a statistically significant difference (*t*-test) between baseline and peak mCA. Although both feedback modalities show similar performance (80% visual, 79% auditory across all runs) the difference between peak and baseline is increasing for auditory (15-35%) whilst decreasing for visual (40%-9%). Because of the likely vision impairment it was unclear if the participant was aware when the trial was ending using visual feedback, particularly for the spaceship game where the spaceship is onscreen and can be manipulated continuously during the run. This in addition to the lack of perceivable visual feedback may be a cause of reduced baseline vs. peak differences during phase 1 whereas an improvement is clear in phase 2. The participant seems more alert during audio feedback, the trial cues/ends were clearer and the musical palette seemed to help alertness (based on visual observation and feedback from family members). Interestingly both the musical and broadband noise feedback results averaged over the last 340 trials of each phase produced the same results (80%) suggesting that even though pink noise is easier to localize than music containing multiple instruments/vocals. Pink noise is much less appealing to listen to than music. In summary, the feasibility of using musical stereo audio feedback in SMR-BCIs has been demonstrated.

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