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Effects of augmentative visual training on audio-motor mapping

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ABSTRACT

The purpose of this study was to determine the effect of augmentative visual feedback training on auditory–motor performance. Thirty-two healthy young participants used facial surface electromyography (sEMG) to control a human–machine interface (HMI) for which the output was vowel synthesis. An auditory-only (AO) group ($n = 16$) trained with auditory feedback alone and an auditory–visual (AV) group ($n = 16$) trained with auditory feedback and progressively-removed visual feedback. Subjects participated in three training sessions and one testing session over 3 days. During the testing session they were given novel targets to test auditory–motor generalization. We hypothesized that the auditory–visual group would perform better on the novel set of targets than the group that trained with auditory feedback only. Analysis of variance on the percentage of total targets reached indicated a significant interaction between group and session: individuals in the AV group performed significantly better than those in the AO group during early training sessions (while using visual feedback), but no difference was seen between the two groups during later sessions. Results suggest that augmentative visual feedback during training does not improve auditory–motor performance.

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1. Introduction

Human–machine interfaces (HMI) serve as augmentative communication pathways that allow users to control external devices. Many currently use electroencephalography (EEG) or surface electromyography (sEMG) to translate signals produced by the brain or muscles into control of an interface (Larson, Terry, Canevari, & Stepp, 2013; Sellers & Donchin, 2006; Trejo, Rosipal, & Matthews, 2006). HMIs using these neurophysiological signals are primarily useful for patients with little remaining motor function, such as those suffering from spinal cord injury, amytrophic lateral sclerosis (ALS) or locked-in syndrome (LIS).

Several different classes of HMIs currently exist in research settings: passive, in which the output of the interface is determined by the involuntary brain activity of the user, and active, in which the user deliberately controls the interface and requires feedback on their performance (Zander, Kothe, Jatzev, & Gaertner, 2010; Zander, Kothe, Welke, & Roetting, 2008). The majority of both active and passive HMIs currently in use call for constant visual monitoring, requiring the user to control their eye movement and shift their gaze during a task. In active HMIs specifically, it is imperative that the user receives feedback on their performance in order to successfully control the interface. Many of the current HMI designs have implemented visual feedback as it offers high performance rates and is easy for new users to learn. However, a constant visual connection is demanding for all users and is infeasible for patients with ALS or LIS who do not have intact vision. In addition, more mistakes were observed during control of a visual HMI when paired with the presentation of distracting visual stimuli among healthy participants (Cincotti et al., 2007). These findings suggest that alternative feedback modalities should be explored in order to make HMIs more user-friendly and practical as a means of communication support. To address the feasibility of removing the visual channel from HMI designs, several studies have proposed both passive and active interfaces to be controlled with the aid of auditory feedback.

Passive designs using auditory stimuli have shown feasibility, typically employing listening paradigms that result in evoked brain responses that are measured using EEG (e.g., P300; Higashi, Rutkowski, Washizawa, Cichocki, & Tanaka, 2011; Lopez-Gordo, Fernandez, Romero, Pelayo, & Prieto, 2012; Schreuder, Blankertz, & Tangermann, 2010). Higashi et al. (2011) measured auditory steady-state EEG responses while participants attended to a tone that was presented to the left or right in each trial, and were able to evoke discriminable EEG responses simply by attending to auditory stimuli on either side. Lopez-Gordo et al. (2012) used an EEG-based BCI that implemented human voice in a similar dichotic listening paradigm and found group average classification accuracy as high as 70%. Another auditory BCI that used spatial hearing as a cue suggested that healthy participants could also use auditory spatial attention to elicit P300 responses for classification (Schreuder et al., 2010). The results of these studies have demonstrated that healthy individuals can control HMIs using auditory stimuli alone. Although these paradigms show relatively high performance, systems that rely on evoked potentials are inherently slow. More research into *active* auditory-only designs is needed.

A few studies have compared users' abilities to control active HMIs using auditory versus visual feedback (Guenther et al., 2009; Larson et al., 2013; Nijboer et al., 2008; Oscari, Secoli, Avanzini, Rosati, & Reinkensmeyer, 2012; Pham et al., 2005). These paradigms have led to mixed results, but the auditory-only groups in these studies performed consistently worse than the groups that received additional visual feedback. For instance, Nijboer et al. (2008) trained healthy subjects to continuously control the amplitude of their EEG sensorimotor rhythms using either auditory or visual feedback. While the average success rate of the participants who received visual feedback was 70%, only half of the participants in the auditory-only group could reach 70% at any point in their training. In addition, the auditory-only group required longer training time on their respective task than the visual group. Pham et al. (2005) examined the ability of healthy participants to control slow cortical potentials (SCPs) when using either auditory or visual feedback. While overall performance was similar between the auditory and visual groups, the experimenters reported that responses in the auditory-only group were more variable; the auditory-only group was less able to self-regulate SCPs. These results suggest that while healthy subjects can learn to use auditory feedback to control active HMIs, they generally have more difficulty controlling HMIs when presented with auditory feedback.