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Brain-computer interface (BCI) operation: signal and noise during early training sessions

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Abstract

Objective: People can learn to control mu (8–12 Hz) or beta (18–25 Hz) rhythm amplitude in the electroencephalogram (EEG) recorded over sensorimotor cortex and use it to move a cursor to a target on a video screen. The recorded signal may also contain electromyogram (EMG) and other non-EEG artifacts. This study examines the presence and characteristics of EMG contamination during new users' initial brain-computer interface (BCI) training sessions, as they first attempt to acquire control over mu or beta rhythm amplitude and to use that control to move a cursor to a target.

Methods: In the standard one-dimensional format, a target appears along the right edge of the screen and 1 s later the cursor appears in the middle of the left edge and moves across the screen at a fixed rate with its vertical movement controlled by a linear function of mu or beta rhythm amplitude. In the basic two-choice version, the target occupies the upper or lower half of the right edge. The user's task is to move the cursor vertically so that it hits the target when it reaches the right edge. The present data comprise the first 10 sessions of BCI training from each of 7 users. Their data were selected to illustrate the variations seen in EMG contamination across users.

Results: Five of the 7 users learned to change rhythm amplitude appropriately, so that the cursor hit the target. Three of these 5 showed no evidence of EMG contamination. In the other two of these 5, EMG was prominent in early sessions, and tended to be associated with errors rather than with hits. As EEG control improved over the 10 sessions, this EMG contamination disappeared. In the remaining two users, who never acquired actual EEG control, EMG was prominent in initial sessions and tended to move the cursor to the target. This EMG contamination was still detectable by Session 10.

Conclusions: EMG contamination arising from cranial muscles is often present early in BCI training and gradually wanes. In those users who eventually acquire EEG control, early target-related EMG contamination may be most prominent for unsuccessful trials, and may reflect user frustration. In those users who never acquire EEG control, EMG may initially serve to move the cursor toward the target. Careful and comprehensive topographical and spectral analyses throughout user training are essential for detecting EMG contamination and differentiating between cursor control provided by EEG control and cursor control provided by EMG contamination.

Significance: Artifacts such as EMG are common in EEG recordings. Comprehensive spectral and topographical analyses are necessary to detect them and ensure that they do not masquerade as, or interfere with acquisition of, actual EEG-based cursor control.

Keywords: Sensorimotor cortex; Mu rhythm; Electroencephalography; Learning; EEG; Brain-computer interface

1. Introduction

Many people with severe motor disabilities require alternative methods for communication and control. Over the past decade, a number of studies have evaluated the possibility that scalp-recorded electroencephalogram (EEG) activity might be the basis for a brain-computer interface (BCI), a new augmentative communication interface that does not depend on muscle control (Birbaumer et al., 1999; Farwell and Donchin, 1988; Kostov and Pollack, 2000; Kubler et al., 1999; Pfurtscheller et al., 1993;

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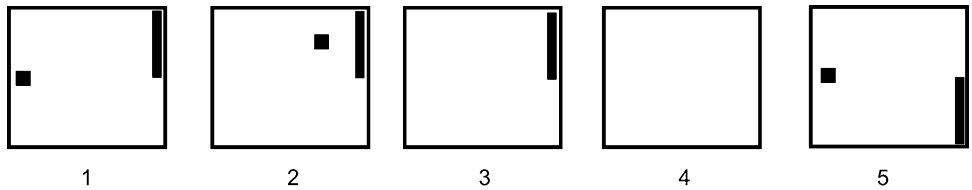

Fig. 1. Cursor control protocol. (1) The target and cursor are present on the screen for 1 s. (2) The cursor begins to move across the screen for 2 s. with its vertical movement controlled by the user. (3) The target flashes for 1.5 s. when it is hit by the cursor. (4) The screen is blank for a 1 s interval. (5) The next trial begins.

Sutter, 1992; Wolpaw et al., 1991; reviewed in Kubler et al. (2001) and Wolpaw et al. (2002)). EEG-based communication systems measure specific features of EEG activity and use the results as control signals. In some systems, these features are potentials evoked by stereotyped stimuli (Farwell and Donchin, 1988; Sutter, 1992). Other systems, such as our own, use EEG features that are spontaneous in the sense that they are not dependent on specific sensory events (Birbaumer et al., 1999; McFarland et al., 1993; Pfurtscheller et al., 1993).

With our current EEG-based communication system, users learn over a series of training sessions to use EEG to move a cursor on a video screen (see McFarland et al. (1997a) for full system description). During each trial, the user is presented with a target along the right edge of the screen and a cursor on the left edge (Fig. 1). The cursor moves across the screen at a steady rate, with its vertical movement controlled by EEG amplitude in a specific frequency band at one or several scalp locations. The user's task is to move the cursor to the height of the target so that it hits the target when it reaches the right edge of the screen. At present, cursor movement is typically controlled either by the amplitude of mu-rhythm activity, which is 8–12 Hz activity focused over sensorimotor cortex, or by the amplitude of higher frequency (e.g. 18–25 Hz) beta rhythm activity, also focused over sensorimotor cortex.

Effective BCI operation has several requirements. First, the user must learn to control the EEG feature, such as mu-rhythm amplitude, that determines cursor movement. Second, signal processing must extract the EEG feature from background noise. For example, we use spatial filtering operations that improve the signal-to-noise ratio (McFarland et al., 1997b). Third, the system must translate this feature into cursor movement so that the user is able to reach each of the possible targets. In our system, cursor movement is a linear function of mu-rhythm amplitude. This linear function has two parameters, an intercept and a slope. We use an adaptive algorithm to select values for these parameters that make all the targets equally accessible to the user (McFarland et al., 1997a; Ramoser et al., 1997).

Electromyographic (EMG) activity from scalp and facial muscles and electrooculographic (EOG) activity from eye movements and eyeblinks may constitute artifacts that obscure the EEG activity used by a BCI system (Goncharova et al., 2003; McFarland et al., 1997a). Increase in EMG from facial muscles is a normal response to difficult tasks (Cohen et al., 1992; Waterink and von Boxtel, 1994). EOG may correlate with cognitive load (Ohira, 1996). EMG and EOG artifacts may masquerade as EEG; and, unless care is taken, some people may actually control cursor movements with these artifacts rather than with EEG. These non-EEG artifacts can be detected and differentiated from actual sensorimotor rhythm control by sufficiently comprehensive spectral and topographical analyses (Wolpaw et al., 2002). This study examines EMG contamination in new BCI users during their first 10 training sessions. The central goal was to explore the relationship between EMG artifacts and the acquisition of EEG control.

2. Methods

2.1. Users

The BCI users were 7 adults (2 woman and 5 men, ages 26–49) (Table 1). Five of these users were from a

Table 1
User characteristics, training parameters, and initial and final performance levels

User	Age	Gender	Disability	Frequency (Hz)	Control locations	Accuracy (%) Session 1	Accuracy (%) Session 10[a]
A	26	M	None	12	C3	93	100.0
B	29	M	None	13	CP3,C4	93	97
C	38	F	None	10	CP4,CP3	81	93
D	40	M	T7 SCI[b]	10	C3	68	96
E	49	F	None	24	C3,CP4	59	80
F	32	M	C6 SCI	12	C3,C4	78	58
G	44	M	None	12	C3,C4	68	48

[a] For Users A–C, who acquired control quickly and moved to the 3-choice format on Session 3 or 4, this value is for the final two-choice session.
[b] Spinal cord injury.