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Centrally controlled heart rate changes during mental practice in immersive virtual environment: A case study with a tetraplegic

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Abstract

A tetraplegic patient was able to induce midcentral localized beta oscillations in the electroencephalogram (EEG) after extensive mental practice of foot motor imagery. This beta oscillation was used to simulate a wheel chair movement in a virtual environment (VE). The analysis of electrocardiogram (ECG) data revealed that the induced beta oscillations were accompanied by a characteristic heart rate (HR) change in form of a preparatory HR acceleration followed by a short-lasting deceleration in the order of 10–20 bpm (beats-per-minute). This provides evidence that mental practice of motor performance is accompanied not only by activation of cortical structures but also by central commands into the cardiovascular system with its nuclei in the brain stem.
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1. Introduction

Two types of changes in heart rate (HR) can be differentiated, an event-related HR deceleration known as orienting response and an event-related HR acceleration known as defence response (for a recent review cf. Sokolov et al., 2002). With respect to information processing two types of HR deceleration responses can be distinguished: an early response related to stimulus anticipation and registration (Lacey and Lacey, 1980; Van der Molen et al., 1989; Bohlin and Kjellberg, 1979) and a second type related to motor preparation. While Bohlin and Kjellberg (1979) favoured the view that expectancy is responsible for the HR deceleration, the work of Brunia (1984), Damen and Brunia (1987) and Papakostopoulos et al. (1990) provide strong evidence that motor preparation is the dominant factor in HR deceleration. Two recent publications are of interest with respect to HR deceleration. During a strong cognitive task, translation of words, the HR displayed a significant deceleration (Pfurtscheller et al., 2007). Imagination of hand or foot movement revealed also HR deceleration (Pfurtscheller et al., 2006a) and similar effects have been reported in the period just preceding different response conditions (Brunia and Damen, 1985) and prior to internally (self)-paced finger movements (Florian et al., 1998).

Beside deceleration also HR acceleration is a frequent response to activation of cortical structures. HR acceleration was not only reported during cognitive processing (e.g. Danilova et al., 1994), but also during mental simulation of movement (Decety et al., 1991; Oishi et al., 2000) and during motor imagery sessions (Papadelis et al., 2007).

In this paper we report on HR data recorded during simulated wheel chair control in an immersive VE. A tetraplegic patient had to "move" a wheel chair in a virtual street by using thought. In particular, movement through the virtual street was controlled by mentally induced electroencephalogram (EEG) bursts.

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2. Methods

2.1. Subject

The patient enrolled in the study is a 30-year old male, who sustained a traumatic spinal cord injury in 1998. He has complete motor and sensory paralysis below the level of the seventh cervical spinal vertebra and an incomplete lesion below cervical level four. Due to the location of this lesion it is likely that only the vagal heart innervation remained completely intact. During an intensive biofeedback training period he learned to induce beta burst at 17 Hz during foot motor imagery (Pfurtscheller et al., 2000).

2.2. EEG- and ECG-recording

One single EEG channel was recorded bipolarly 2.5 cm anterior and posterior to the electrode position Cz over the foot representation area (ground electrode was placed on the forehead). The EEG was amplified and band-pass filtered between 0.5 and 30 Hz with a biosignal amplifier (Guger technologies OEG, Graz, Austria). The electrocardiogram (ECG) was recorded bipolarly from the thorax (corresponding to an Einthoven II recording) with the same amplifier and filtered between 0.5 and 100 Hz. A 50 Hz notch filter was applied before the biosignals were digitized with a sampling rate of 250 Hz. The real-time processing was performed under Simulink (MathWorks, Inc., Natick, USA) using rtsBCI (Scherer, 2004–2007).

A single logarithmic band power feature was estimated from the ongoing EEG after digitally band-pass filtering (15–19 Hz, Butterworth filter of order 5), squaring, averaging (moving average) the samples over the past second and log-transforming. A simple threshold was used in the online experiments to distinguish between foot movement imagination (control or intentional state) and rest (non-control or non-intentional state). Whenever the band power exceeded the threshold a foot motor imagery was detected and the signal was used to control the VE (for details see Leeb et al., 2007).

2.3. Virtual environment and experimental paradigm

The tetraplegic patient was placed with his wheel chair in the middle of a multi-projection based stereo and head-tracked VE system of the type commonly known as a “CAVE” (Cave Automatic Virtual Environment, Cruz-Neira et al., 1993). The actual system used was a Trimension ReaCTor (SEOS Ltd. West Sussex, UK) that has a three back-projected vertical screens (3 m × 2.2 m) and a floor screen (from a ceiling mounted projector) (3 m × 3 m) controlled by a Silicon Graphics Onyx 2. The VE depicted a virtual street populated with 15 virtual characters (avatars), which were lined up along the street (see Fig. 1).

The task of the participant was to “move” the wheel chair from avatar to avatar until the end of the virtual street was reached. This translation of the virtual wheel chair along the street was accomplished by imagining that he was moving his paralyzed feet. He moved forward only while foot motor imagery was being detected in the EEG signal. In addition he was required to stop in just front of every avatar before actually reaching it. After a while, at his own choice, the subject could imagine another foot movement and start to virtually walk again, until the end of the street was reached. The avatars were placed on the same positions in all runs of the experiment and the participant started from the same point. In the case of 15 correct stops in one run, the performance was 100% (for details see Leeb et al., 2007). Six runs were carried out on one day.

2.4. Calculation of heart rate (HR) changes

The first step in ECG processing is to detect the QRS (ventricular contraction) complexes in the ECG signal. The QRS complexes determine the distance in time from one heart contraction to the next one (RR-interval). The QRS complexes were detected automatically based on an algorithm using a filter bank to decompose the ECG signal into various subbands (for details see Afonso et al., 1999). From the RR-intervals the instantaneous heart rate (IHR) was calculated between consecutive RR-interval samples. After selection of IHR trials with 5 s prior and 5 s after each detected EEG band power maximum, averaging was performed across the trials of each run. For the statistical evaluation of HR changes in relation to the band power maximum (“0” on x-axis in Fig. 2C) the HR was determined in each IHR trial at times “0”, 3 s before and 3 s thereafter and a Wilcoxon-test was performed. The time point 3 s after the band power maximum corresponds approximately to the maximum of the post-imagery HR deceleration (see Fig. 2C).

3. Results

3.1. Performance measure and EEG changes

The results of the experiments are summarized in Table 1. Altogether the tetraplegic subject spent about 30 min in the VE

Fig. 1. Picture of the virtual street with the avatars and the tetraplegic subject in the wheel chair.

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