# Phasic heart rate response in virtual environments

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**Abstract**

*Heart rate responses induced by motor imagery were investigated in 4 subjects in a series of experiments with a Brain-Computer Interface (BCI). The goal of the BCI experiment was either to control a bar on a PC monitor or to move forward within a virtual environment (VE). In the first case all subjects displayed a HR decrease during motor imagery in the order of 2 – 5 %. The thought-based control of VE resulted in a heart rate increase in 2 subjects and a heart rate decrease in the other 2 subjects. The heart rate acceleration in the VE is interpreted as effect of mental effort and motivation.*

*Keywords* — ***Heart rate, Motor imagery, Virtual environment, Brain-Computer Interface***.

## 1. Introduction

Preparation or planning of a self-paced movement is accompanied by a deceleration of the heart rate [1, 2]. Because similar neuronal structures are involved in motor execution and motor imagery [3] it is of interest to investigate heart rate (HR) changes in the Brain-Computer Interface (BCI) experiments with motor imagery as mental strategy and different types of feedback (FB). The objective of the study is to investigate HR changes while the BCI is used to control (i) a simple bar on a PC monitor and (ii) a virtual environment (VE) with the goal to move e.g. forward in a virtual street as far as possible.

## 2. Materials and Methods

The study was performed on 4 healthy student volunteers aged 23 – 30 years (mean age 26.7 years). The subjects took part in a series of BCI experiments over some months with the goal of achieving control over their brain activity [4] for mental control of a virtual environment (VE) [5]. Two mental strategies were used: either imagination of right hand vs. left hand or right hand vs. foot/leg movements. In the majority of these experiments, in addition to the EEG, the electrocardiogram (ECG) was also acquired from the thorax which was sampled at 250 Hz, stored and used for off-line processing.

### 2.1. Experimental paradigm

Each subject took part in a number of BCI training runs in Graz. Thereafter, runs were performed in London in a multi-projection based stereo and head-tracked VE system commonly known as a “CAVE” [6] and finally, control runs were made in Graz again. In each run, the subject had to imagine movements in response to an auditory cue stimulus, given either as single beep or as double beeps. Each trial lasted about 8 seconds, during which at second 3 the cue-stimulus appeared. The subject was instructed to imagine the indicated movement over the next 4 seconds while feedback was given during that time.

The data of VE sessions in the Cave in London and the final control sessions on the PC monitor in Graz are reported in this paper. The EEG trials were used for the discrimination of the 2 mental states of motor imagery [4]. Details can be found elsewhere [5].

### 2.2. Electrocardiogram processing and calculation of HR changes

After the detection of the QRS-complexes in the ECG a R-R time series was extracted. From this time series the instantaneous heart rate was calculated by linear interpolation between consecutive RR-interval samples and resampling with 4 Hz. After selecting of 8-s instantaneous HR trials with 3s prior to the cue-stimulus, averaging was performed across the 40 trials of each run. The result is an event-related HR-time course together with the sample-by-sample intertrial standard deviation (SD).

## 3. Results

The results obtained in all 4 subjects are summarized in Table 1. All subjects displayed a HR decrease (increase of the R-R intervals) during motor imagery under control condition with FB on a PC monitor. A characteristic example from one subject is displayed in Fig. 1A. In the VE 2 subjects displayed also a HR decrease, but 2 subjects a HR increase. A detailed analysis of one BCI experiment in the CAVE with a HR increase revealed the following: A correct classification of foot motor imagery in the EEG data resulted in a forward moving in the VE, while a false classification of hand motor imagery resulted in a backward moving. In the former case the positive FB was accompanied by a weak HR change (Fig. 1B). In the latter case, when the subject was not successful to move forward and disappointed, the HR displayed an increase of about 4.5 bpm (beats-per-minute) (see Fig. 1C).

| subject | condition | RRref [ms] mean | RRref [ms] SE | RRresp [ms] mean | RRresp [ms] SE | change [%] | p |
|---|---|---|---|---|---|---|---|
| S1 | control | 716 | 2,31 | 740 | 2,43 | 3,32 | <0,001 |
| | VE | 708 | 2,77 | 723 | 2,97 | 2,12 | <0,001 |
| S2 | control | 976 | 4,76 | 1004 | 4,45 | 2,87 | <0,001 |
| | VE | 812 | 2,93 | 846 | 2,62 | 4,19 | <0,001 |
| S3 | control | 865 | 3,88 | 901 | 3,51 | 4,12 | <0,001 |
| | VE | 954 | 4,91 | 904 | 7,20 | -5,19 | <0,001 |
| S4 | control | 796 | 4,49 | 841 | 4,84 | 5,65 | <0,001 |
| | VE | 765 | 7,56 | 753 | 7,54 | -1,63 | <0,05 |

**Table 1: Mean R-R interval and standard error (in ms) in the reference interval before the cue-presentation (RRref) and during motor imagery (RRresp) for all subjects and conditions. In addition changes (in %) between the RRref and RRresp and their significances are displayed.**

## 4. Discussion

Motor imagery is accompanied by a slight but significant heart rate deceleration in the order of 2 – 5 %, when simple feedback is given on a computer monitor. This is not surprising, because motor imagery involves similar cortical structures to those activated during preparation of voluntary movement [7] and heart rate decelerates when a subject prepares a self-paced movement [2]. A logical consequence of increased motor cortex excitability is that it should propagate down to the brain stems spinal cord and motor neuron levels. It is also known that motor imagery activates not only neural structures in primary motor cortex [7] but is also accompanied by an increased corticospinal and spinal reflex pathway excitability [8]. In the brain stem the parasympathetic system is activated which results in a slowing of the heart rate.

A surprising result is the heart rate acceleration in 2 subjects observed in the VE experiments. Thought-based forward moving in a VE is a great challenge for a subject and therefore the motivation is higher as in standard BCI experiments with a PC. We can hypothesize, that a negative FB in the CAVE (e.g. by moving backwards instead of forwards) increases the mental effort and the motivation of the subject with the goal to reach a change of the classification result and reveal thereby a positive FB, e.g. by moving forward in the VE. As a result of this increased mental effort (in close connection with the motivation to move forward as far as possible) the sympathetic system becomes activated and the HR increases.

The study suggests that neocortical structures involved in motor imagery impinge upon brain stem cardiovascular nuclei and modify the heart rate. In general, motor imagery is associated with an HR deceleration. Subcortical structures related to motivational and other psychological processes activate the sympathetic system and reveal a HR acceleration.

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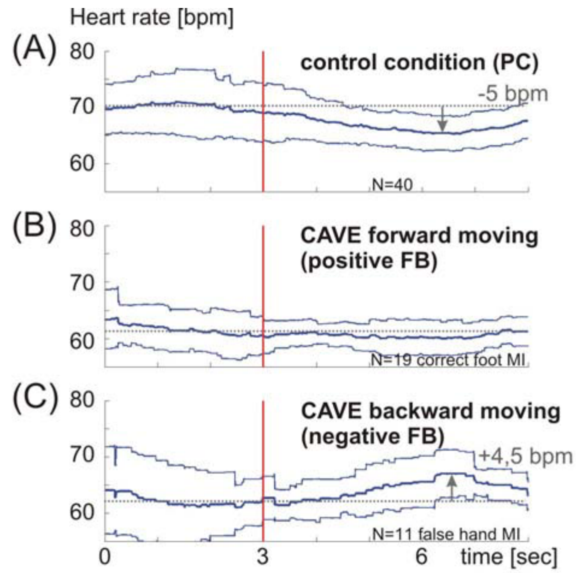


**Figure 1: Heart rate (HR) changes (±SD) in bpm for a control experiment (A) without CAVE and an experiment within the CAVE (B and C). HR changes during positive feedback (FB) and forward moving (correct classification of foot motor imagery) are displayed in (B) and HR changes during negative FB and backward moving (false classification of hand motor imagery) are displayed in (C).**

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