FACE-RELATED ERP IS INFLUENCED BY CARDIAC AFFERENT INFORMATION

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Abstract. The visceral system can influence consciousness and emotions. In this paper, we investigated whether the processing of short-term emotional stimuli along different phases of the cardiac cycle is selectively regulated. Emotional and neutral faces were presented to the volunteers during cardiac systole, when the release of blood from the heart causes arterial baroreceptors to centrally signal the strength and time of the heartbeat, and in diastole, the period between heartbeats when the baroreceptors are at rest. Participants passively observed the faces appearing in the oddball paradigm in immersive virtual reality (VR). Combining electroencephalography and electrocardiography, cardio synchronous ERP was recorded. The ERP data at the occipital Oz electrode demonstrate the dependence of emotional stimuli in respect to the cardiac cycle. ERP in VR were higher during diastole than systole. More specifically, the cardiac phase influenced late component P300 of the ERP, did not influence early P100 and affected P200 only to angry face. This new evidence that events related to cardiac function can modulate emotional perception in virtual reality might be one more prime example of how body feedback shapes emotions.

Keywords: face, facial expression, ERP, cardiac cycle, virtual reality.

List of Abbreviations

EEG – electroencephalogram
ECG – electrocardiogram
ERP – event-related potential
VR – virtual reality

Introduction

The evoked potentials of the brain in response to an external stimulus depend on the properties of the stimulus, as well as on the state of the brain (Gelbard-Sagiv *et al.*, 2018). The functional states of body organs, such as the heart, can also influence the perception of external stimuli (Al *et al.*, 2020). For example, several studies have reported that the timing of the cardiac cycle (eg, systole and diastole) affects the perception of visual (Sandman *et al.*, 1977), auditory (Saxon, 1970), pain (Gray *et al.*, 2010) and emotional stimuli (Gray *et al.*, 2012).

Areas of the brain that are involved in the formation and presentation of interoception also support emotional and attentional processes. These brain areas include the anterior cingulate gyrus, insular cortex, amygdala, and specific brainstem nuclei (Craig, 2002; Gray *et al.*, 2007; Saleh & Connell, 1998). Among these, the amygdala is particularly associated with enhanced emotional memory (Bradley & Sambuco, 2022) and arousal-induced attention capture.

«Peripheral» theories of emotion emphasize the centrality of bodily responses to the subjective experience of emotion. It is assumed that emotional feelings arise as a result of physiological changes and interoception (Garfinkel *et al.*, 2014). Cardiac activity, as one of the most important sources of interoceptive signal for the limbic predictor, according to (Barrett & Simmons, 2015), limits the activity of predictor neural networks to ascending visceral sensory afferent inputs. This hypothesis is consistent with the hypothesis of other authors about interoceptive predictors in the emotional brain (Al *et al.*, 2020; Seth & Friston, 2016).

Increasing evidence indicates that events related to cardiac function can modulate conscious emotion perception, fundamental questions remain open. Current research is targeting the mechanisms that link the heart to the brain, using the task of emotional perception with electroencephalography (EEG) recordings.

Materials and Methods

Participants

Thirty healthy volunteers, all males, 19-21 years, all of them were right-handed, had normal or corrected-to-normal vision. All of them were similar in psychophysiological parameters identified by preliminary psychophysiological testing. All participants were provided written informed consent prior to the study. The study was approved by the Bioethics Committee of the Samara State Medical University. Three participants did not complete registrations, and therefore their data was not included in the analysis.

EEG-Recoding

EEG was registered monopolarly with 64 electrodes by the 128-channel EEG recording system «BP-01030 BrainAmp Standart128» (manufactured by BrainProducts, Germany) with the ActiCap system of active electrodes. A special textile electroencephalographic cap was used to fix the electrodes. Electrodes were located according to the «10-10%» system (modification of the international «10-20» system (Jasper H., 1957). A special gel was placed under each electrode to achieve the resistance less than 8 kΩ between the electrodes and the scalp surface. We used two electrodes to identify oculomotor artifacts on EEG: HEOG – FT10 (fixed on the skin of the right cheekbone), VEOG – AF7. ECG was recorded in augmented unipolar right arm lead by Box EIB64-A amplifier (manufactured by BrainProducts, Germany). The sampling frequency of the signal was 500 Hz.

Stimuli

Stimuli were 3D models of young male human faces with different facial expressions: neutral, positive and negative. As a etalon facial expressions we selected images of faces depicting Neutral, Happy and Angry emotions from the FACES database (Max Planck Institute for Human Development, Germany) (Ebner *et al.*, 2010). We used the custom developed software (powered on Unity) to convert images of faces into 3D models. 3D models of faces were standardized in size, head tilt, distance and color texture.

Task and design

The study of brain evoked potentials was performed in immersive virtual reality. HTC VIVE Eye pro helmet (two screens 3.5 inch each; resolution:1440 x 1600 for each eye, refresh rate 90 Hz; viewing angle 110 degrees) was used for the demonstration. Stimuli were presented on a dark gray background in the oddball paradigm. The duration of the stimulus presentation was 200 ms, the interval between stimuli was 400 ms, during which the screen was empty (Fig. 1). The subjects were instructed to observe at the center of the virtual scene, where stimuli appeared. An explicit response to the emotional stimulus was not required. The stimuli were grouped into sets of six objects in one recording cycle. One record contained 50 cycles, each record was repeated 4 times on different experimental days.

Preprocessing

EEG analysis was conducted using the Brainstorm software (Tadel *et al*., 2011). The EEG data were filtered in the range from 1 to 40 Hz. To correct artifacts eye movements, we used JADE independent component analysis (ICA). Eye movement components were removed according to their topography and correlation with EOG. For ERP analysis 700 ms EEG fragments were used, starting 100ms before the stimulus onset. Each epoch and channel were individually baselined by subtraction of the mean of the baseline period from -50 to -2 ms before the stimulus. The averaged ERP in all sessions were marked separately for different types of facial expressions and phases of the cardiac cycle (diastole and systole). ECG fragment duration of 270 ms preceding the R wave was defined as a diastole, after the R wave with a duration of 270 ms as systole (Fig. 2).

The ERP's amplitudes were homogeneous (according to the Levene test), but did not have a normal distribution (according to the Shapiro-Wilk test), so we used the nonparametric Wilcoxon test to analyze data. Statistical analysis was performed in Jamovi v 2.2 software.

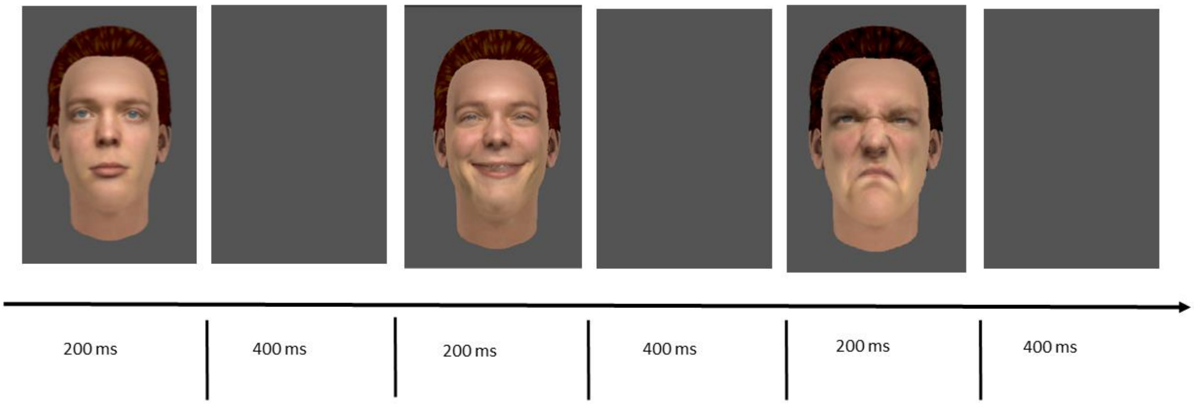

Fig. 1. Timeline of one experiment's trial. The 3D-face was presented for 200 ms, the gray background was presented for 400 ms. The sequence of 3D-face presentations was random

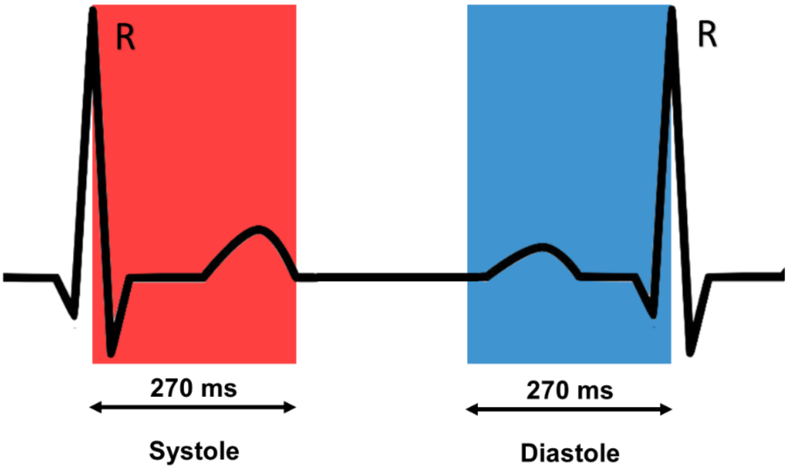

Fig. 2. ECG fragments (systole and diastole), that was used for ERP analysis

Results

The most pronounced difference in average of ERP for different stimuli among all electrodes was found at the Oz electrode, and all the following ERP analysis are showed using the data recorded at Oz electrode. To compare the reactions in response to the presentation of emotional facial expressions in different phases of the cardiac cycle in VR, we analyzed the averaged amplitudes P100, P200, P300 ERP components.

The amplitude of the P100 component in VR in response to the presentation of neutral, happy and angry facial expression did not show a significant difference along systole and diastole. The P200 component showed a significant difference only for the emotional negative face (angry). The P200 amplitude during diastole was significantly higher than during systole in VR ($p = 0.025$). The P200 amplitude for a neutral and positive face did not shows significant difference.

The amplitude of the P300 component in VR in response to the presentation of different 3D-faces show a significant difference between systole and diastole for all facial expression. More specifically in VR the P300 ERP component was higher during diastole than systole in response to neutral ($p = 0.003$), happy ($p = 0.002$), angry ($p = 0.028$) facial expressions (Table 1, Fig. 3).

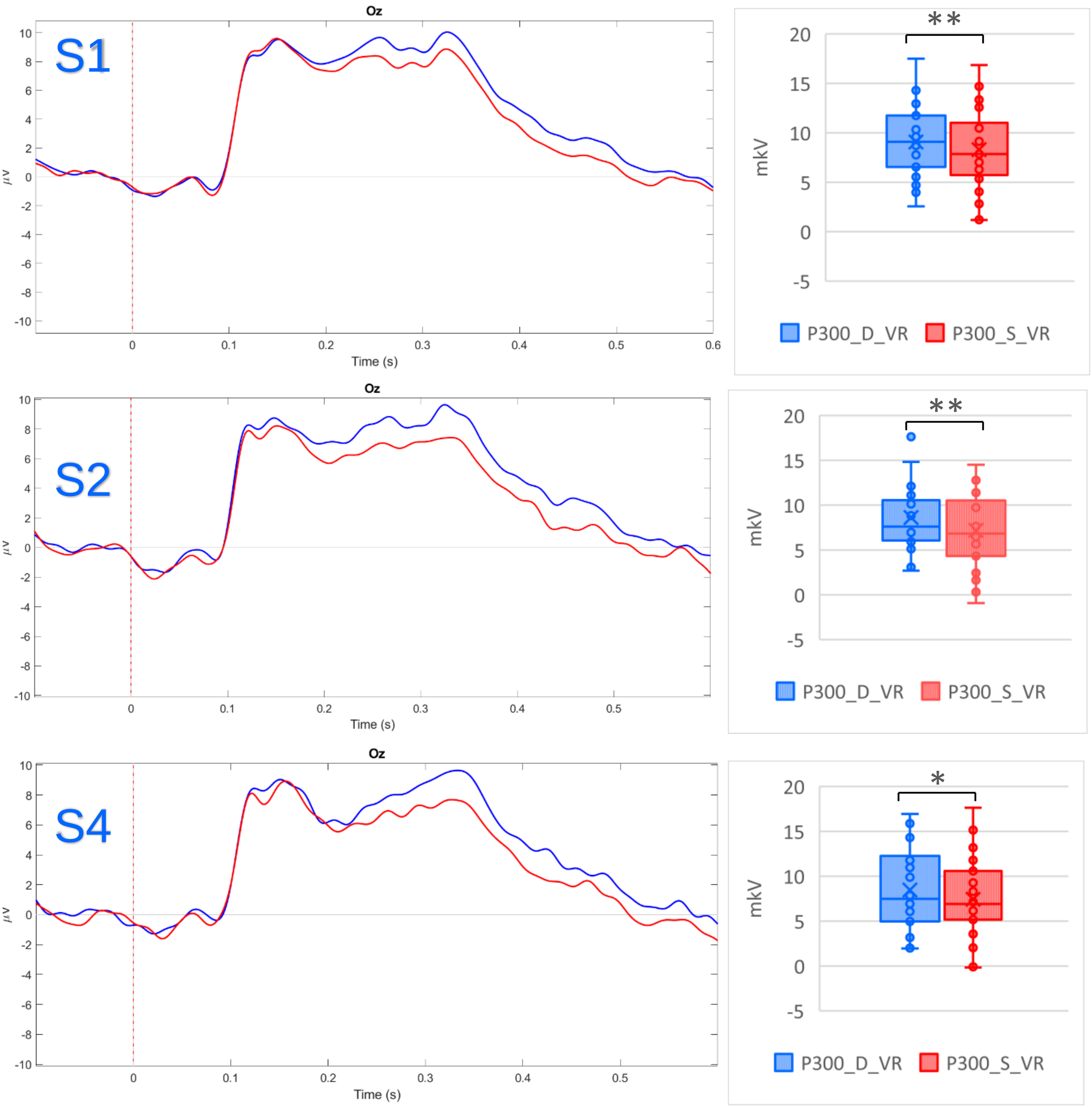

Fig. 3. Averaged ERPs and boxplots of P300 amplitude in response to facial expressions of emotionally neutral (S1), positive (S2) and negative (S4) faces in the "oddball" paradigm in VR. The red line/box is the systole, the blue line/box is the diastole. *$p < 0.05$, **$p < 0.005$, N = 27

Table 1

Descriptives of ERP amplitudes P100, P200 and P300 waves in response to presentation 3D facial expressions in virtual reality along phases of cardiac cycle

P100	Mean	Median	SD	p-value
P1_D_VR_P_S1	7.10	6.45	3.97	0.259
P1_S_VR_P_S1	7.47	7.01	3.24	
P1_D_VR_P_S2	6.90	6.14	3.60	0.663
P1_S_VR_P_S2	6.66	6.47	3.22	
P1_D_VR_P_S4	6.96	7.28	4.30	0.849
P1_S_VR_P_S4	6.83	6.23	3.38	

The end of the table 1

P200	Mean	Median	SD	p-value
P2_D_VR_P_S1	8.38	7.76	3.27	0.983
P2_S_VR_P_S1	8.37	7.29	3.36	
P2_D_VR_P_S2	7.50	7.20	3.66	0.269
P2_S_VR_P_S2	6.89	7.73	3.65	
P2_D_VR_P_S4	**7.67**	**6.64**	**3.73**	**0.025**
P2_S_VR_P_S4	**7.03**	**5.67**	**3.45**	
P300				
P3_D_VR_P_S1	**9.07**	**9.09**	**3.54**	**0.003**
P3_S_VR_P_S1	**8.30**	**7.85**	**3.90**	
P3_D_VR_P_S2	**8.62**	**7.60**	**3.97**	**0.002**
P3_S_VR_P_S2	**7.20**	**6.83**	**4.09**	
P3_D_VR_P_S4	**8.47**	**7.49**	**4.44**	**0.028**
P3_S_VR_P_S4	**7.43**	**6.91**	**4.27**	

Note: D – diastole, S – systole, S1 – neutral face, S2 – happy face, S4 – angry face

Discussion

This study was aimed to compare ERP in response to 3D faces in immersive virtual reality along phases of cardiac cycle. The presented ERP data demonstrates the dependence of emotional stimuli in respect to the cardiac cycle. More specifically, ERP in VR were higher during diastole than systole. Furthermore, the cardiac phase influenced late component P300 of the ERP, didn't influence early P100 and affected P200 only to angry face.

Modulation of the ERP response in different phases of the cardiac cycle may be associated primarily with the genesis of interoceptive signals during the cardiac cycle. During systole, baroreceptors in the aorta and carotid sinus increase signals to sensory and integrative centers in the medulla oblongata and pons (Rau & Elbert, 2001). During diastole, the period between heartbeats, baroreceptors are not activated and not afferented to the same brainstem nuclei. Baroreceptor afferents project further up the neuroaxis to the thalamus, the periaqueductal gray, and to the limbic system structures, amygdala, anterior cingulate gyrus and insular cortex (Fredrikson *et al.*, 1998; Gray *et al.*, 2012; Zhang & Oppenheimer, 2000). Given the close relationship between peripheral physiological and emotional states, we hypothesized that baroreceptor activation directly affects the processing of emotional perception.

According to the hypothesis of a number of authors, cardiac activity, as one of the sources of ascending visceral sensory afferent signals for the limbic system, limits the activity of prognostic neural networks (Barrett & Simmons, 2015; Seth & Friston, 2016). Each repetitive heartbeat and its accompanying pulse wave are treated as predictable events and are attenuated by the brain to reduce the chance that these endogenously generated signals being mistaken as external stimuli (Barrett & Simmons, 2015; Seth & Friston, 2016).

The P200 and P300 components of ERP is an indicator of conscious and cognitive awareness (Polich, 2007). The decreased P200 amplitudes (to negative face) and P300 amplitude and lower sensitivity to visual stimuli (both neutral and emotional) during systole may indicate a less efficient propagation of neuronal activity to higher levels of processing (Al *et al.*, 2020). Accordingly, suppression of cortical activity at the later stages of emotional stimulus processing can be expected to lead to decreased P300 amplitude.

This work is the first study of face-related ERP in immersive virtual reality along the phases of cardiac cycle. We have demonstrated how late waves of face-related ERP is modulated by afferent cardiac activity. This new evidence that events related to cardiac function can modulate emotional perception, and could be one more a prime example how body feedback shapes emotions.

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