Phasic Induction of Bioelectromagnetic Heart-Brain Coupling Through Emotional Stimuli

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Abstract

The heart generates bioelectromagnetic fields that induce heart-brain coupling (HBC), which is associated with various perceptual, cognitive, and emotional functions. The amplitude of the heart's cyclical electrocardiography (ECG) potential varies within each heartbeat for different phases of the heart's contraction, affecting the HBC. This study aimed to explore the phasic variations in the HBC by examining the spatiotemporal Heartbeat-Evoked Potentials (HEPs) in the brain, corresponding to the ECG, in response to emotional stimuli of Heart Lock-In (HLI), positive self-talk (PT) and negative self-talk (NT). Paced breathing at six breaths per minute was used to achieve a relaxed state for improved HBC. The study found a significant attenuation of the HEPs during both NT and PT conditions. However, the HBC was significantly enhanced during the heart's ventricular repolarization for HLI, PT and NT conditions. These findings suggest that increases in cardiovascular afferent signals, which have been previously shown to modulate brain functions and increase heart-brain synchronizations, may be the cause of increased HEP amplitudes. The study confirms the presence of HBC and affirms that the heart plays a significant role in modulating the brain's functioning and activity.

Keywords: afferent signals, Bioelectromagnetic, Electrocardiogram; Heart-Brain Coupling (HBC); Heartbeat Evoked Potential (HEP); Heart Lock-In (HLI); Phasic Induction

1. Introduction

Bioelectromagnetics is the generation of the electromagnetic field from living tissue [1] . The electrical impulses in the human body generate these electromagnetic fields. This phenomenon has been used for improving health and consciousness [2-5]. The most prominent bioelectromagnetic fields are produced by the heart [6]. The effect of heart-brain coupling (HBC) is reported in various studies which shows that the heart plays a major role in modulating the activity of higher brain regions engaged in perceptual, cognitive, and emotional processing [7, 8]. Therefore, heart activity has a significant role in modulating a variety of human experiences and behaviors [8-11], as well as in modulating brain activity by synchronizing it with electrocardiography (ECG) [12-14].

Bioelectromagnetic tools are used to study the human brain such as magnetoencephalography, transcranial magnetic stimulation, transcranial electric stimulation, and electroencephalography (EEG) [15]. Damiano Azzalini et al. [16] described that Heartbeat-Evoked Potentials (HEPs), which are found in EEG, can be used to get insight into how intrinsic stimuli such as visceral stimuli and emotions, can modulate cognition. HEPs are commonly used to investigate the heart-brain couplings during various emotions [17]. They are event-related potentials of the brain's electrical responses that are induced by the heart's electromagnetic waves. Hence, HEPs are time-locked to the R-wave of the ECG, which represents the ventricular depolarization, or ventricular contraction in the cardiac cycle [18, 19]. The HEPs waveforms are created by averaging the EEG recording at each electrode site by using R-peak in the ECG waveform at the timing signal. HEPs modulations reflect not only the accuracy of heartbeat perception [20], but also other processes related to heart-brain communication, such as body awareness [21], emotional experience, motivation, attention, pain perception, and stress [18, 22-24]. HEPs are an electrophysiologic measures of the cortical processing of afferent information, which is associated with individual heartbeats, and have drawn more attention from researchers in recent years. Interestingly, the HEPs amplitudes increase when individuals focus their attention on feeling their heartbeat [25, 26]. Higher or lower HEPs amplitudes indicate an increase or decrease in afferent impulses from the heart to the brain [6] and potential interference with the flow of afferent signals throughout the brain due to the activation of neural activity, such as during anxiety or stress.

The heart-rate variability (HRV) during different emotional stimuli affects the HBC and hence HEP amplitudes, thereby establishing the important role of vagal afferents in modulating brain function [8, 27-33]. MacKinnon [30] discovered significant increase in HEPs amplitude over central EEG electrodes during resonant breathing with six breaths per minute as compared to spontaneous breathing. Furthermore, two recent investigations [34, 35] found that participants' cardiac interoceptive accuracy might be improved by holding their breath. There are several studies [10, 14, 36], that demonstrate the use of the Heart lock-in (HLI) technique for producing a more coherent and higher amplitude HRV pattern which is associated with an increase in vagal afferent traffic to the brain and enhances the synchronization of the heart and brain. The HEPs amplitude is usually increased during tasks related to focus or enhanced attention [25, 26, 37]. During the somatosensory tasks, the amplitude of HEPs are reduced over the parietal region demonstrating that somatosensory signals are involved in the physiological mechanisms underlying heartbeat processing and perception [38, 39]. However, the spatiotemporal induction of HBC is yet to be explored to understand how each of the different regions of the brain gets affected by HRV caused by different emotional stimuli.

The objective of this study is to explore how the phasic nature of ECG results in a variable induction of HBC. We hypothesized that the HBC induction would be strongest during ventricular depolarization due to the high amplitude of the R-wave in this phase. Moreover, we hypothesized that emotional stimuli may cause a decrease in HEP amplitude due to increased neural processing in the higher brain regions. An increased HBC resulting from the HLI and paced breathing would be related to higher amplitudes of HEPs.

2. Methods

2.1 Participants

Twenty-four participants took part in the study, 20 of whom were females (age: 40 ± 8.85 years) and 4 were males (age: 47±10.6 years). The inclusion criteria required that volunteers be healthy, with no personal or family history of neurological, psychiatric, or somatic disease, and to have refrained from using any recreational drugs in the previous week. Each participant signed informed consent, and the nature and purpose of the investigation, as well as the procedures involved and potential benefits and risks, were explained to them. Participants were allowed to ask questions and were informed that their participation in the study was voluntary and could be terminated at any time. The study followed the protocol and procedure established by the HeartMath Institute USA.

2.2 Experimental Setup

Each participant was asked to follow the same protocol. Figure 1 explains the experimental procedure of the study. At the start of the experiment, participants were informed about all four emotional conditions (i.e., HLI, BR, PT, NT). A proven autobiographical script technique was used to induce emotional states [40, 41]. Participants were asked to sit in a seated position with their eyes closed. Participants were instructed to sit quietly for the next 5 minutes without talking, and not engage in intense mental or emotional activity. Following this, baseline (EC) was recorded in eyes closed state for three minutes. EEG and ECG were recorded during all conditions i.e. EC, HLI, BR, PT and NT respectively. In between each condition Participants were allowed to rest for 5 minutes.

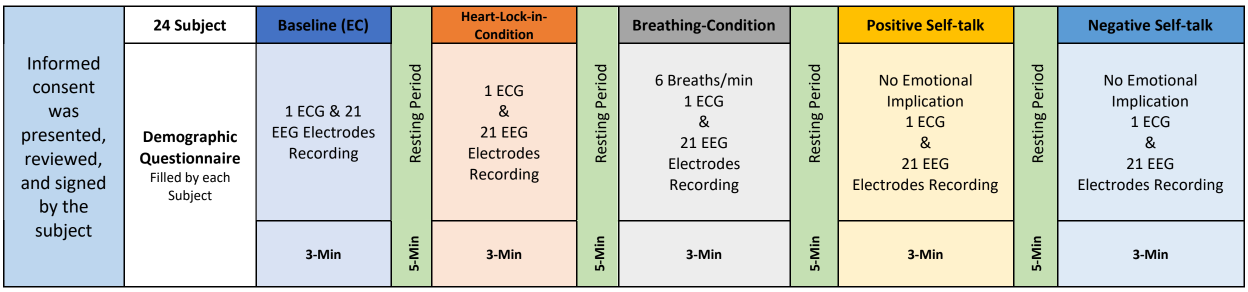

Figure 1 Data Collection Procedure for 24 Subjects, during baseline (EC) Condition, Heart-Lock-in Condition, Breathing Condition, Positive self-talk condition, and Negative self-talk Condition.

Heart Lock-in Exercise (HLI): HLI was performed for 10-minutes with eyes closed. Participants had been trained in and practiced the technique before the data collection. Following instructions were given to participants for the HLI exercise.

Step 1: Focus your attention on the area of the heart. Imagine your breath is flowing in and out of your heart or chest area, Breathing a little slower and deeper than usual. Find an easy rhythm that's comfortable. After around 45 seconds, the following step was read to them: Activate and sustain a regenerative feeling such as appreciation, care, or compassion. After about 30 seconds it was said: if you find your mind wandering throughout the HLI, just gently. Step 3: refocus your attention on the area of the heart and breathe in feelings of appreciation, care, or compassion. Following this, they were instructed in the last step: Radiate that renewing feeling to yourself and others [3-5]

Paced Breathing: Using an auditor breath pacer, the Participants were instructed to breathe at a rhythm of five-second on the in-breath and five-seconds on the out-breath. They were instructed to keep their eyes closed during this time [30, 42, 43].

Positive Self-talk: Data was collected for 3-minutes with eyes closed. They were instructed to think about some of their positive thoughts about themselves, such as, I can handle anything that comes my way, I am good at many things, I appreciate all the friends I have, I love my life, and so on [30, 36, 44].

Negative Self-talk: Participants were asked to keep themselves engaged in negative self-talk for the next 3-minutes. They were instructed to think negatively such as, nothing ever goes my way, I don't have talent, I'm just not creative, no one likes me, and so on, they were instructed to pick one or two recurring negative things they used to say usually and really to think about them. They were instructed to close their eyes [36, 44, 45].

EEG and ECG Recording: Brain and heart activity was recorded using Free-Caps from Institute for EEG Neurofeedback (IFEN) Neuroscience and Brainmaster Discovery 24E from 19 scalp locations i.e. (FP1, FP2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz, Pz, ECG), using Brain-Avatar Software from Brainmaster Technology Inc. system. Following the 10-20 international system at a sampling rate of 256 Hz [8]. Both EEG and ECG signals were recorded during all conditions. Data were acquired in a quiet and ventilated room.

2.3 Data Processing

The raw EEG and ECG data were analyzed with EDF browser, and IFEN ERP Analyzer signal processing software, [46-48]. The recording of ECG and 19 EEG channels were filtered by FIR band-pass filter (1-30 Hz) by the toolbox EEGLAB for MATLAB. All recordings were individually and manually examined to remove any artifacts, and EEG data were segmented according to R-peaks from -0.2 to 0.6 seconds [49]. The HEPs were analyzed by using the software IFEN ERP Analyzer [46]. Grand averages of HEPs were calculated for each electrode site [50-53]. The Whole-time window was divided into eight segments relative to the timing of the R-Wave of the ECG, i.e., T1[-0.2 - -0.1], T2[-0.1-0.0], T3[0.0-0.1], T4[0.1-0.2], T5[0.2-0.3], T6[0.3-0.4], T7[0.4-0.5], T8[0.5-0.6] seconds, to analyze modulation of HEPs amplitudes with the help of topo-plots of each segment. The RR intervals and Heart rate was calculated by using R-DECO (MATLAB Toolbox). R_DECO was used as a graphical user interface to detect and adjust R-peaks. The R-peaks in R-DECO are discovered using an adaption of the Pan-Tompkins algorithm. Instead of employing all of the previous technique's pre-processing steps, the new algorithm merely uses an envelope-based procedure to flatten the ECG and improve the QRS complexes. The graphical user interface was used to access all operations, and the analysis results were exported as Excel files [54, 55].

2.4 Statistical Analysis

Paired t-test was performed on the grand averages to test for difference in the amplitude of HEPs at each EEG site for the Heart-lock-in condition, the breathing condition, the positive self-talk condition, the negative self-talk condition as compared to baseline (EC), and BR-HLI, NT-PT conditions. A cluster-based permutation test was applied to assess the significance of HEPs and their topographical distribution over the scalp. To analyze pre and post-stimulus heart rate and inter-beat Intervals (RR), the R_DECO code was used [54]. Paired T-test was also performed to see the significance of the pre-stimuli and post-stimuli R-R intervals and heart rate.

3. Results

The comparison of HEPs between HLI (green color) and BASE (blue) conditions for all electrodes is shown in Figure 2. HEPs amplitude for the left prefrontal lobe, anterior temporal, right frontal lobe, mid-temporal, and occipital region is significantly higher for the HLI condition as compared to the baseline (EC) condition.In addition, In addition, for later periods, HEPs where the amplitude shifts to positive direction, during the HLI, mainly for posterior, central, and temporal regions there were significantly large values of HEPs when compared with baseline (EC) condition.

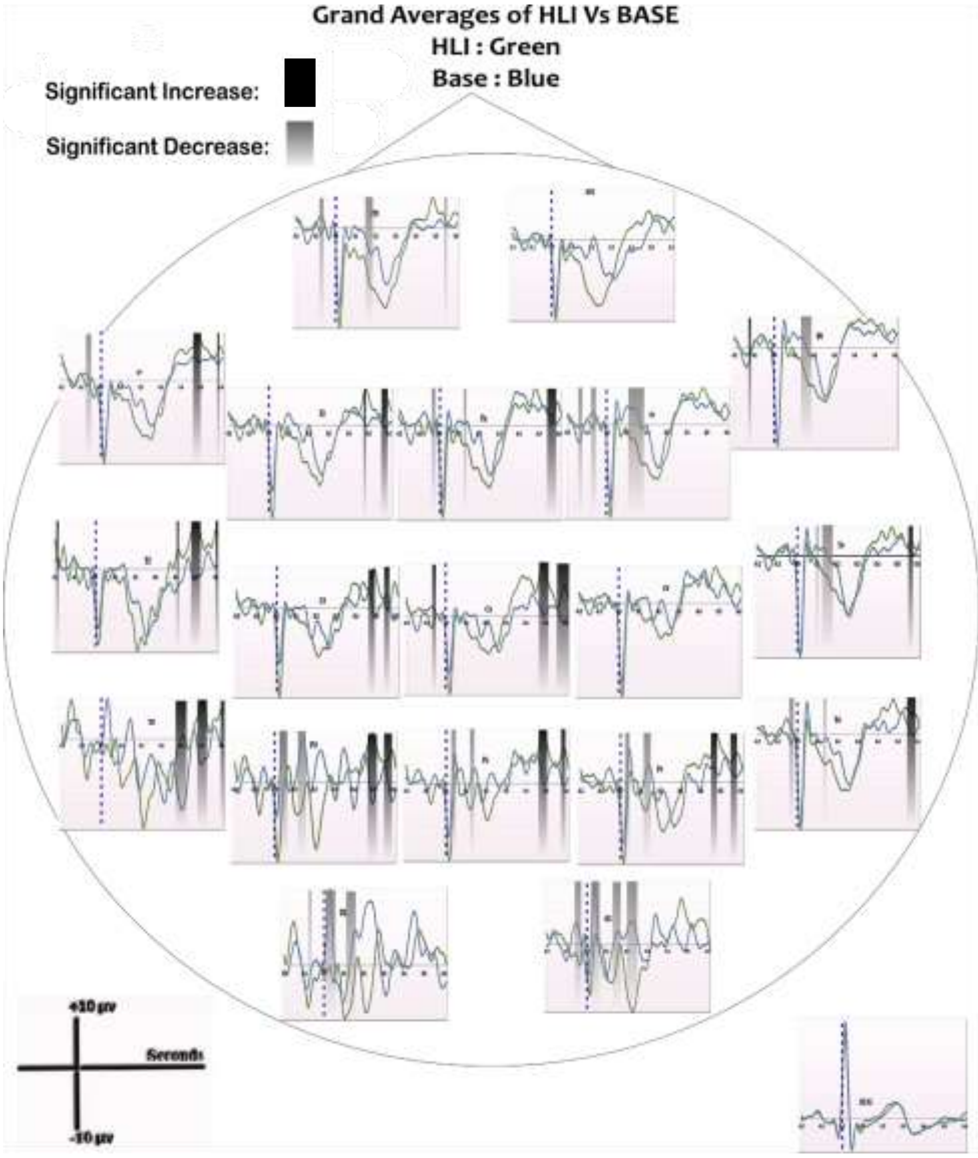

Figure 2: Heartbeat Evoked Potential for HLI condition with respect to the baseline (EC) condition. HEPs amplitude of HLI is represented with green color whereas the baseline (EC) is with blue color. Black and gray bars show Significant differences for baseline (EC). Black bars show a significant increase in HLI compared with the baseline (EC). Whereas the gray bar shows a significant decrease in HLI compared with the baseline (EC).

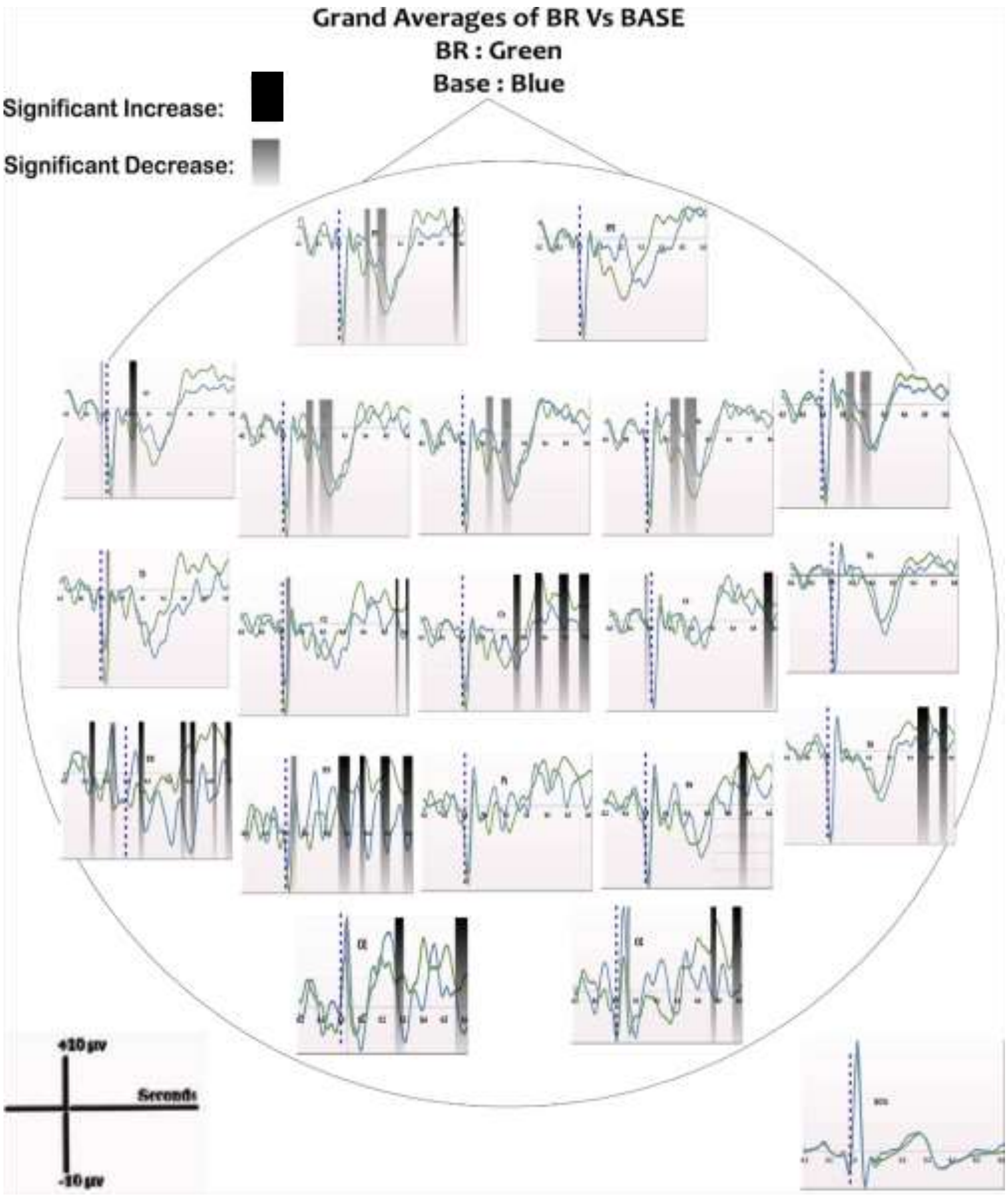

Figure 3: Heartbeat Evoked Potential for Breathing condition concerning the baseline (EC) condition. The HEPs amplitude of BR is represented with green color whereas the baseline (EC) is with blue color. Black and gray bars show Significant differences for baseline (EC). Black bars show a significant increase for BR compared with baseline (EC). Whereas the gray bar shows a significant decrease for BR compared with the baseline (EC).

The comparison of HEPs between paced breathing (BR) (green color) and baseline (EC) (blue) conditions for all EEG sites is shown in Figure 3. The HEPs amplitude for the early periods in the frontal region during the negative going section of the HEP is significantly larger for the BR condition as compared to the baseline (EC). In addition,for late periods, where the HEPs shifts to a positive direction mainly for posterior and central regions had significantly larger values of HEPs for the BR condition when compared with baseline (EC).

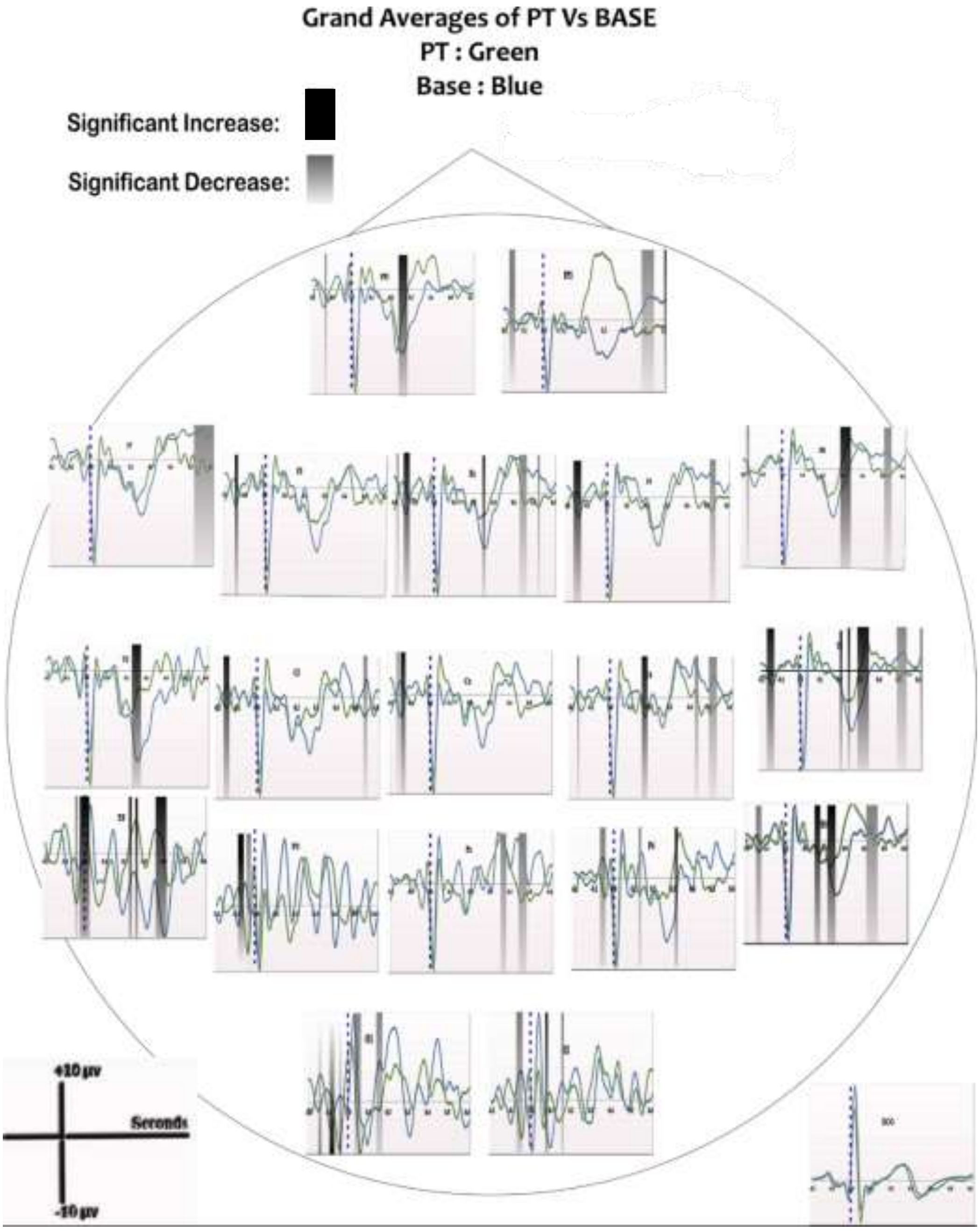

Figure 4: Heartbeat Evoked Potential for PT condition with respect to the baseline (EC) condition. HEPs amplitude of PT is represented with green color whereas the baseline (EC) is with blue color. Black and gray bars show Significant differences for baseline (EC). Black bars show a significant increase for PT compared with baseline (EC). Whereas the gray bar shows a significant decrease in PT compared with the baseline (EC).

The comparison of HEPs between positive self-talk (PT) (green color) and EC baseline (blue) conditions for all electrodes is shown in Figure 4. HEPs amplitude for the right prefrontal, left anterior temporal, midline parietal, the right occipital region during the negative section of the HEP is significantly higher for the PT as compared to the baseline (EC) condition. However, HEPs amplitude is positive for the Left-prefrontal region, right anterior temporal, frontal lobe region, for central, parietal, and temporal regions with significantly large positive values of HEPs for the NT condition when compared with baseline (EC) condition.

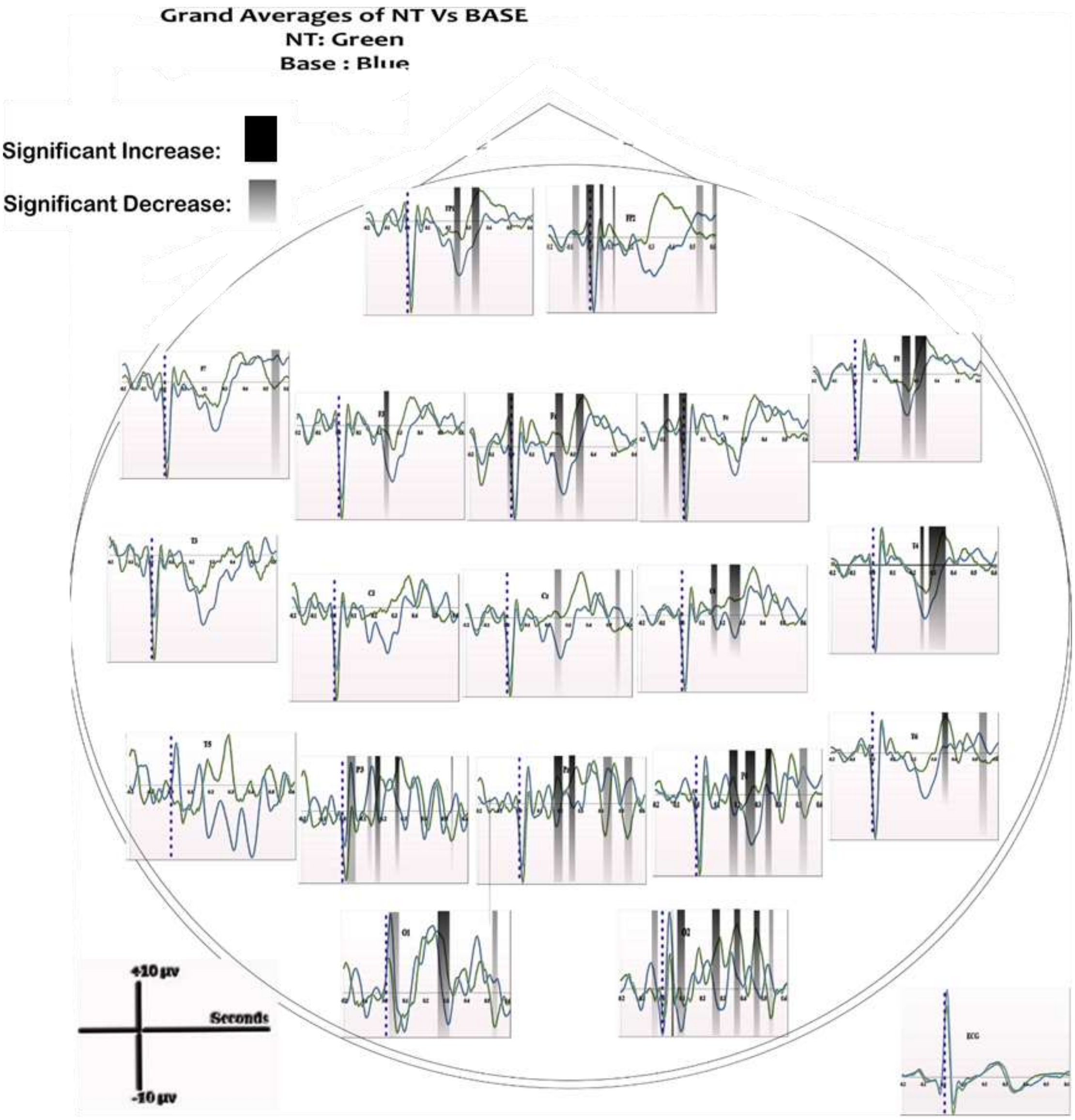

Figure 5 **Heartbeat Evoked Potential for NT condition with respect to the baseline (EC) condition. HEPs amplitude of NT is represented with green color whereas the baseline (EC) is with blue color. Black and gray bars show Significant differences for baseline (EC). Black bars show a significant increase for NT compared with baseline (EC). Whereas the gray bar shows a significant decrease in NT compared with the baseline (EC).**

Heartbeat Evoked Potential for negative self-talk (NT) condition with respect to baseline (EC) condition was also calculated. As shown in figure 5, HEPs amplitude is negative for both conditions, mainly for left anterior temporal, for midline central, for late periods, for midline Parietal, for right Parietal (P4), right Posterior temporal, and the occipital regions. HEPs amplitude is positive for a time period [0.0-0.4] seconds, for the posterior region, for the right center, right temporal, and occipital regions, with significantly large positive values of HEPs for the NT condition when compared with baseline (EC) condition. HEP for BR condition for HLI condition is calculated. HEPs amplitude for the midline parietal and right parietal regions is negative and this negative HEPs is significantly higher for BR as compared to the HLI condition. However, HEPs amplitude for BR is positive for the left prefrontal region, the right anterior temporal region, the right mid-temporal region, the posterior temporal region, the left parietal region, and the occipital region with significantly large positive values of HEPs for BR condition when comparing with HLI condition. Heartbeat Evoked Potential for NT condition with respect to resting PT condition is calculated. HEPs amplitude for the right prefrontal region, frontal region, temporal region, parietal region, and occipital region is positive and this positive HEPs is significantly higher for the NT condition as compared to the EC (Base) condition. The figures for NT-base, BR-HLI, and NT-PT can be seen in the supplementary document.

Spatiotemporal Changes in HEPs Amplitude

Figure 5(a) shows Spatiotemporal changes of HEPs amplitude for all four conditions (HLI, BR, PT, and NT) and baseline the time periods: T1[-0.2- -0.1], T2[-0.1-0.0], (note that T1 and T2 occur before the ECG R-Wave) T3[0.0-0.1], T4[0.1-0.2], T5[0.2-0.3], T6[0.3-0.4], T7 [0.4-0.5] and T8[0.5-0.6]. The HEPs amplitude is strongest in T5, T6, and T7 segments for HLI condition, breathing, positive self-talk, and for negative self-talk.

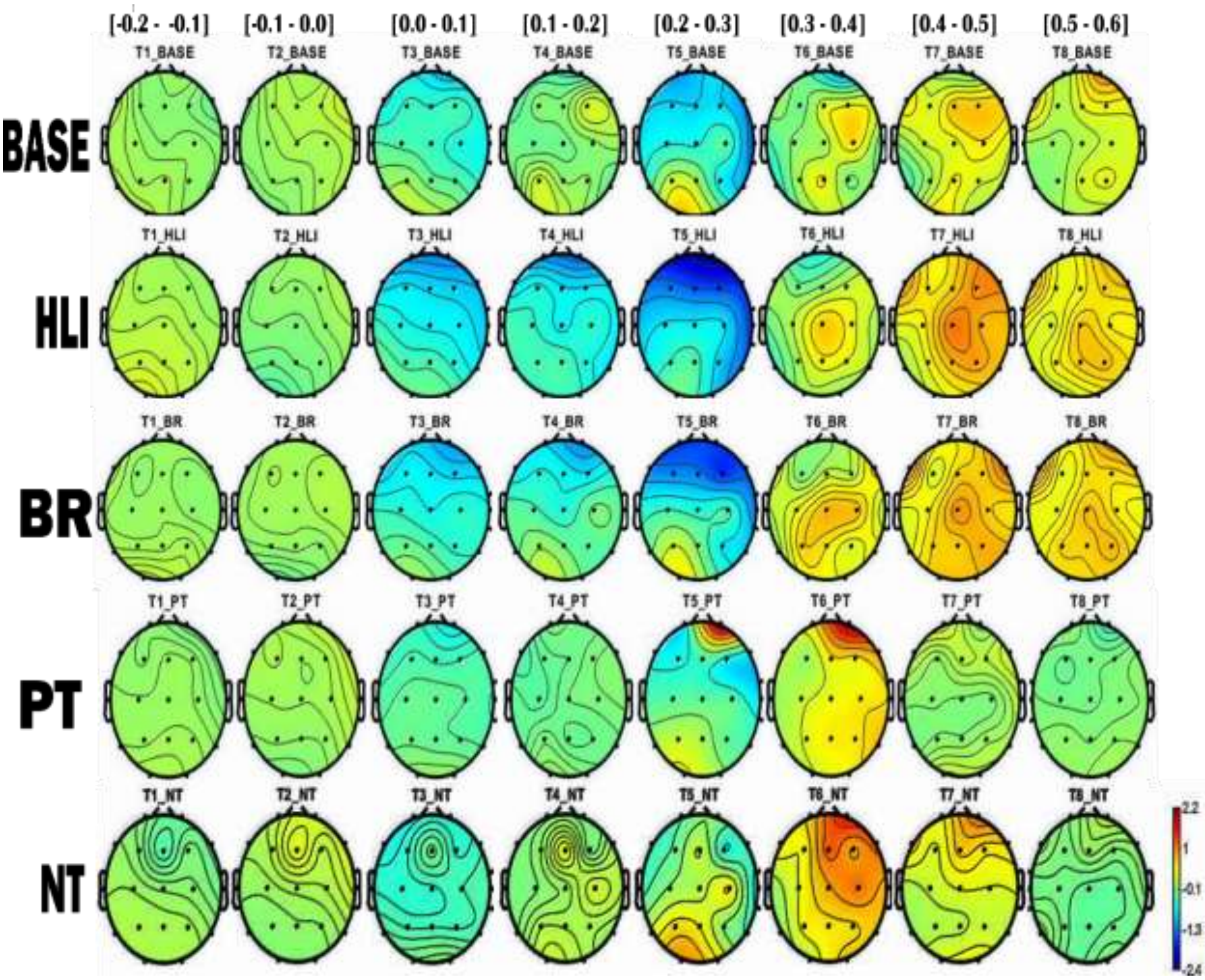

Figure 5-1(a): Spatiotemporal changes of HEPs amplitude for all four conditions (HLI, BR, PT, and NT) overtime period T1 [-0.2 - -0.1], T2[-0.1 – 0.0], T3[0.0-0.1], T4[0.1-0.2], T5[0.2-0.3], T6 [0.3-0.4], T7[0.4 - 0.5] and T8[0.5 – 0.6] seconds. The blue color represents the reduction in HEPs amplitude as compared to the baseline (EC) period, while the red color represents the enhancement in HEPs amplitude.

Comparison of Spatiotemporal HEPs amplitude between HLI-Base condition, across the cardiac cycle

As shown in Figure 5(b), during depolarization of atria (atrial systole begins) at T1 and during the first phase of ventricular systole at T2, no change is observed in HEPs amplitudes for the HLI condition as compared to the base. At T3 when the second phase of ventricular systole begins, the decrease in HEPs amplitude is noticed for the HLI condition as compared to the baseline (EC). This decrease is specifically for the right prefrontal region, the left mid-temporal region, the central region, the parietal region for the posterior temporal region, the occipital region, and the midline central and parietal region. At early ventricular diastolic T4 and late ventricular diastole T5, the decrease in HEPs amplitude is noticed for the HLI condition as compare to the the resting state baseline (EC). This modulation in HEPs amplitude is dominant and global at T4 and T5. In R-wave section, a lot of change in HEP amplitude is noticed for

HLI and BR conditions, where we expect the most increase in afferent signals. Whereas, no difference is observed for NT and PT condition at T3 and T4. At T5[0.2-0.3] and later, when the blood pressure wave arrives at the brain, which takes about 240 milliseconds, there is a significant change in HLI and BR. At T6, T7, and T8, when atrial systole begins, isovolumetric relaxation starts, and all chambers of the heart are relaxed, the increase in HEPs amplitude is noticed for the HLI condition as compared to the baseline (EC). AT T6, HEPs amplitude is positive for the right prefrontal region, for the mid-temporal region, the left central region for the posterior temporal region for the left parietal region, and the midline central region. This increase, in HEPs amplitude for pre and post stimuli is global at T7 and T8.

Comparison of Spatiotemporal HEPs amplitude between BR-Base condition, for cardiac cycle

In Figure 5(b), during depolarization of atria (atrial systole begins) at T1 and during the first phase of ventricular systole at T2, no change is noticed in HEPs amplitude for the BR condition as compared to the base. At T3 when the second phase of ventricular systole begins, the decrease in HEPs amplitude is noticed for the BR condition as compared to the baseline (EC). This decrease is specifically for the prefrontal region, frontal region, anterior temporal region, right mid-temporal region, right central region, parietal region, right posterior temporal region, the occipital region, midline frontal, central and posterior region. At early ventricular diastolic T4 and late ventricular diastole T5, a decrease in HEPs amplitude is noticed for the BR condition for the base. This decrease is dominant and global at T4 for BR compared with base whereas, at T5, HEPs amplitude is decreased for the prefrontal region, for the frontal region, for the anterior temporal region, for the midline frontal, and right occipital region. At T6, T7, and T8, when atrial systole begins, isovolumetric relaxation starts, and all chambers of the heart are relaxed, the increase in HEPs amplitude is noticed for the HLI condition as compared to the baseline (EC). This increase, in HEPs amplitude for the base, is global and dominant at T6 and T8. Whereas at T7, HEPs amplitude is increased for the prefrontal region, the anterior temporal region, the mid-temporal region, the posterior temporal region, the occipital region, the parietal region, the left central region, for midline central and parietal region.

Comparison of Spatiotemporal HEPs amplitude between PT-Base condition, for cardiac cycle

In Figure 5(b), during depolarization of atria (atrial systole begins) at T1 and during the first phase of ventricular systole at T2, no change is noticed in HEPs amplitude for the PT condition as compared to the baseline (EC). At T3 when the second phase of ventricular systole begins, no significant change in HEPs amplitude is noticed for the PT condition as compared to the base. At early ventricular diastolic T4, a little decrease is noticed in the amplitude of HEPs for PT when comparing with the baseline (EC) condition, this HEPs amplitude is decreased for the frontal region for the right anterior temporal region for mid-temporal regions, for right regions, for the parietal region, for the left occipital region, for midline frontal, central and parietal region. At T4, a little increase is noticed for the PT condition when compared with the base for the prefrontal region. During late ventricular diastole, at T5, a little increase in HEPs amplitude is noticed for the HLI condition for the baseline (EC). HEPs amplitude is the increase for the prefrontal region, the frontal region, the anterior temporal region for the left mid-temporal region, the left posterior temporal region, and the midline frontal region. At T6, when atrial systole begins, an increase in HEPs amplitude is noticed for PT when compared with the baseline (EC) condition. HEPs amplitude is Positive, dominant for the frontal region, for the right regions of the brain as compared to the left region, and the mid-frontal, central and parietal regions. At T7 and T8, isovolumetric relaxation starts, and all chambers of the heart are relaxed, decrease is noticed in the amplitude of HEPs for PT for baseline (EC) condition. This decrease is more dominant and global at T8 for PT when compared with the baseline (EC) condition.

Comparison of Spatiotemporal HEPs amplitude between NT-Base condition, for cardiac cycle

In Figure 5(b), during depolarization of atria (atrial systole begins) at T1 and during the first phase of ventricular systole at T2, no change is noticed in HEPs amplitude for the NT condition as compared to the base. At T3 when the second phase of ventricular systole begins, no significant change in HEPs amplitude is noticed for the NT condition as compared to the baseline (EC). At early ventricular diastolic T4, a little increase is noticed in the amplitude of HEPs for the NT when compared with the baseline (EC) condition. During late ventricular diastole, at T5, an increase in HEPs amplitude is noticed for the NT condition for the base. HEPs amplitude increases for the central region, occipital region, midline parietal, and central region. At T6, when atrial systole begins, an increase in HEPs amplitude is noticed for NT when compared with the base condition. HEPs amplitude is Positive, dominant, and global at T6. At T7 and T8, isovolumetric relaxation starts, and all chambers of the heart are relaxed, the decrease is noticed in the amplitude of HEPs for PT for the baseline (EC) condition. This decrease is more dominant and global at T8 for NT when compared with the baseline (EC) condition.

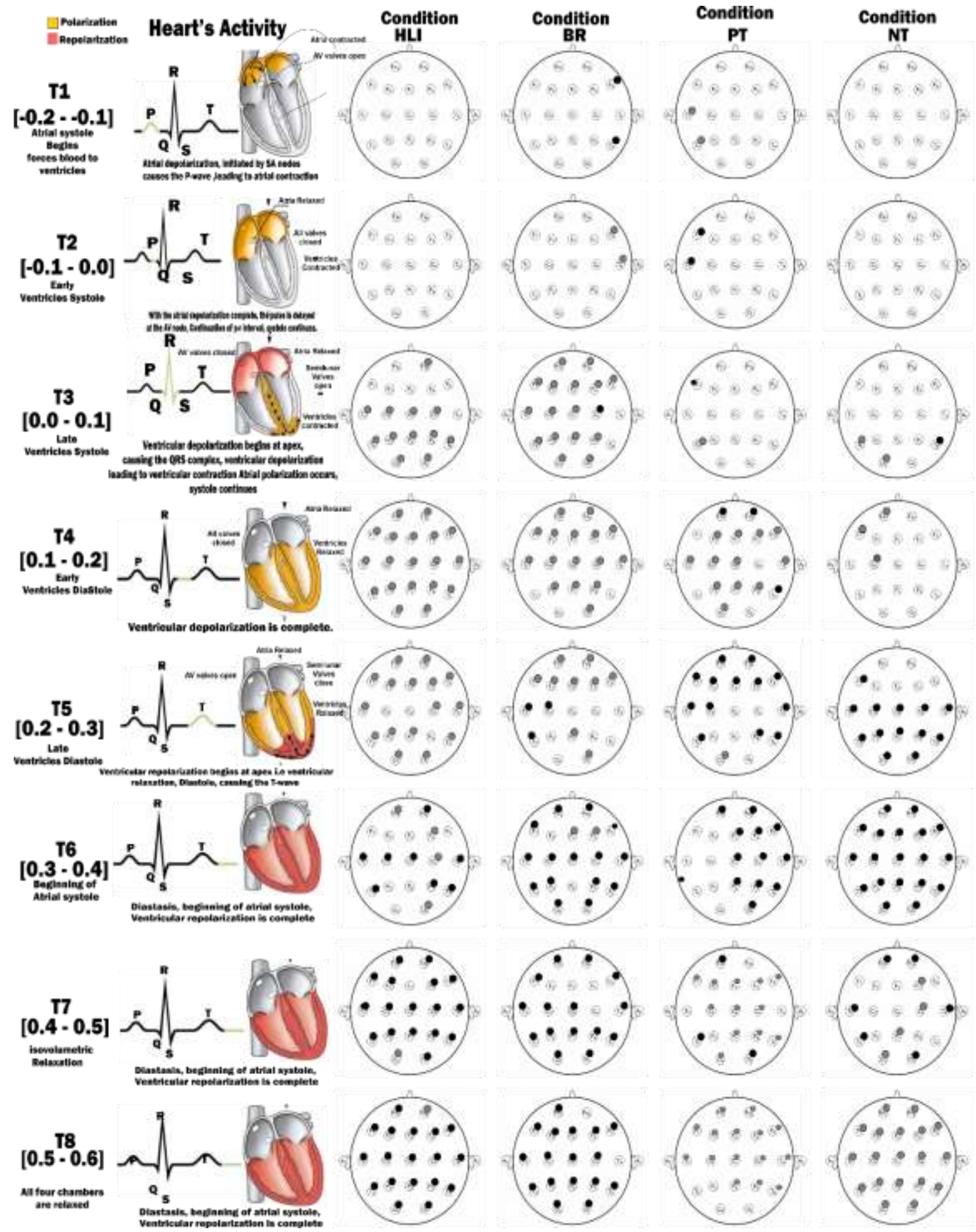

Figure 5 (b): Comparison of four conditions with baseline (EC) condition over time-period T1 [-0.2 - -0.1], T2[-0.1 – 0.0], T3[0.0-0.1], T4[0.1-0.2], T5[0.2-0.3], T6 [0.3-0.4], T7[0.4 - 0.5] and T8[0.5 – 0.6] seconds, for the cardiac cycle. The significant increase in HEPs amplitude is shown with filled black circles for each electrode while a significant decrease in HEPs amplitude is presented with a grey-filled circle. The first column shows phases of Heartbeat action and their electrical electricity recorded as ECG. The highlighted area of the PQRST wave is representing the simulated active phase of the heart. The polarization of the heart is represented with yellow color while depolarization is explained with red color for all periods.

Comparison of Spatiotemporal HEPs amplitude between BR-HLI condition, for cardiac cycle

During depolarization of atria (atrial systole begins) at T1, during the first phase of ventricular systole at T2, and at T3 when the second phase of ventricular systole begins no change is noticed in HEPs amplitude for BR condition as compared to HLI (Figure 5 (c)). At early ventricular diastolic T4, an increase in BR is noticed when compared with HLI. Whereas for late ventricular diastole at T5, the increase in HEPs amplitude is noticed for the BR condition and for HLI condition. This increase in HEPs amplitude is dominant for the posterior region as compared to the frontal region at T5. At T6, when isovolumetric relaxation starts, an increase in HEPs amplitude is noticed for BR when compared with HLI. This increase is dominant for the central region for BR as compared to HLI. At T7, when atrial systole begins, a decrease in HEPs amplitude is noticed for the BR condition as compared to HLI. HEPs amplitude is decreased for the right region as compared to the left region for the BR condition compared with HLI. At T8, all chambers of the heart are relaxed, and an increase in HEPs amplitude is noticed for the BR condition as compared to HLI. HEPs amplitude is increased for the prefrontal region, the left anterior temporal, the left central region, the left posterior temporal region, the parietal region, and the occipital region.

Comparison of Spatiotemporal HEPs amplitude between NT-PT condition, for cardiac cycle

In Figure 5(c), during depolarization of atria (atrial systole begins) at T1, during the first phase of ventricular systole at T2, at T3 when the second phase of ventricular systole begins and At early ventricular diastolic T4, no change is noticed in HEPs amplitude for NT condition as compared to PT. Whereas for late ventricular diastole at T5, the increase in HEPs amplitude is noticed for the NT condition for the PT condition for the posterior region whereas an increase in HEPs amplitude is noticed for the PT condition for the NT condition for the frontal region. At T6, when isovolumetric relaxation starts, an increase in HEPs amplitude is noticed for NT when compared with PT. This increase is dominant and global. At T7, when atrial systole begins, an increase in HEPs amplitude is noticed for the NT condition as compared to the PT condition. HEPs amplitude is increased for the frontal region as compared to the posterior region for the NT condition compared with the PT condition. At T8, all chambers of the heart are relaxed, and no change in HEPs amplitude is noticed for the NT condition as compared to the PT condition.

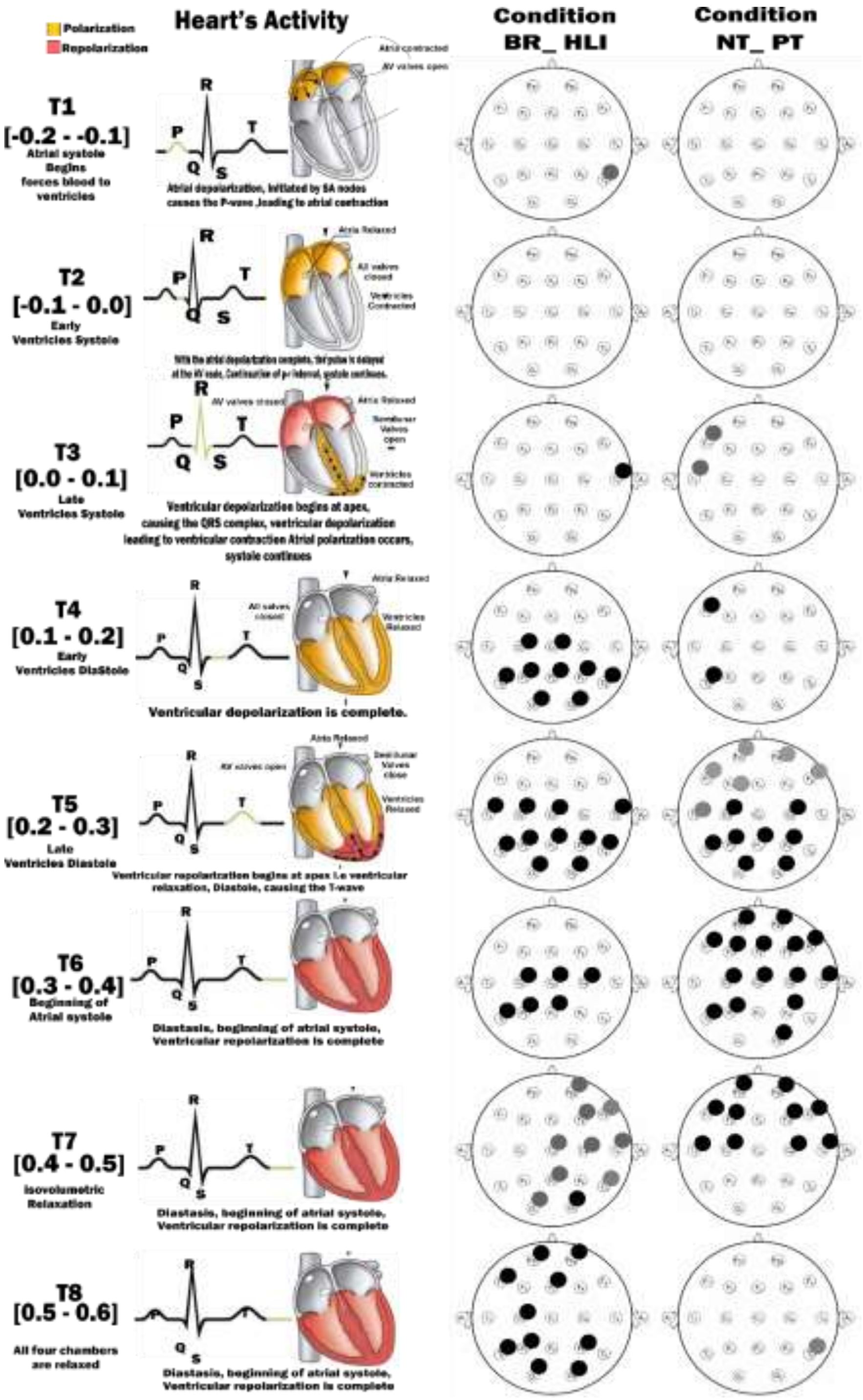

Figure 5(c): Comparison of four conditions with baseline (EC) condition over a time period T1 [-0.2 - -0.1], T2[-0.1 – 0.0], T3[0.0-0.1], T4[0.1-0.2], T5[0.2-0.3], T6 [0.3-0.4], T7[0.4 - 0.5] and T8[0.5 – 0.6], for the cardiac cycle. The significant increase in HEPs amplitude is shown with filled black circles for each electrode while a significant decrease in HEPs amplitude is presented with a grey-filled circle. The first column shows phases of Heartbeat action and their electrical electricity recorded as ECG. The highlighted area of the PQRST wave is representing the simulated active phase of the heart. The polarization of the heart is represented with yellow color while depolarization is explained with red color for all periods.

R-R Intervals

Figure 6 shows RR intervals for all conditions. The significant difference between baseline (EC) and other conditions is shown with '*' on the top of the bar graph for a particular condition. It can be noticed that the RR interval is significantly decreased for HLI (p= 0.002, t= -3.53) and PT (p= 0.03, t= -2.061) conditions as compared to baseline (EC)

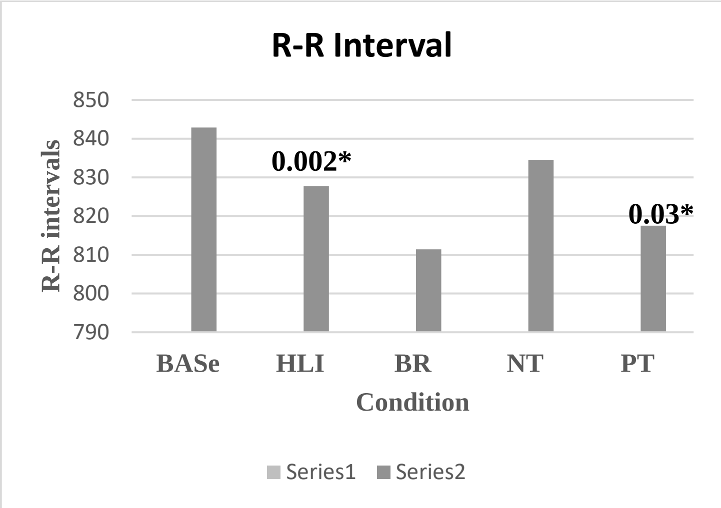

Figure 6: Comparison of RR intervals for all conditions. The significant difference between baseline (EC) and other conditions is shown with '*' on the top of the bar graph for a particular condition.

Number of Beats

Figure 7 shows a Comparison of numbers of beats for the first 3 minutes in pre-stimuli (BASE) and post-stimuli for all four conditions (HLI, BR, NT & PT), the t-test is applied, and there is no significant difference in all the conditions compared with baseline (EC).

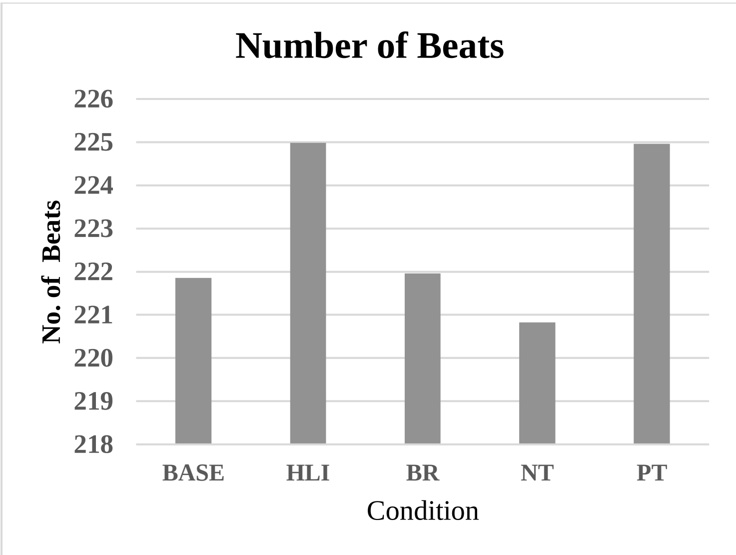

Figure 7: Comparison of numbers of beats for the first 3 minutes in pre-stimuli baseline (EC)and post-stimuli for all four conditions (HLI, BR, NT & PT)

4. Discussion

This study affirmed the presence of phasic induction of bioelectromagnetic heart-brain coupling (HBC). As hypothesized, the highest HEP amplitudes corresponded to the R-wave. The current study supports previous research findings indicating that the heart contributes to and modulates the activity of the brain [9, 56]. Efferent cardiac activation of both sympathetic and parasympathetic activity plays a major role in the arousal of emotional conditions, although most focus on sympathetic activations and increased heart rate [32]. Our findings show the affective conditions influence brain responses to cardiac interoceptive signals, as observed by modulation in HEP amplitude.

Higher HEPs amplitude globally for the BR condition compared with the baseline (EC) condition demonstrates the increased inflow of afferent information in the brain. On the other hand, the process of self-talk engaged the neuro-circuits that are interfering with the flow of afferent signals. Previous research found that negative emotions increase and engage the amygdala, insula, and other limbic structures by increasing sensitivity to negative stimuli. [57-59]. The results of our study demonstrated that the HLI technique, which increased HEP and therefore an increase in afferent traffic [10, 45], caused synchronization of heart with the brain. Recent theoretical and experimental research has suggested that heart-focused attention is connected with greater heart-brain synchrony, providing support to the role of afferent traffic in heart-brain connections [11, 14, 60, 61].

This theory holds that, in the HLI technique, the heart generates increased order in the HRV patterns and thus in the patterns of afferent traffic with can modify how the body's systems organize internal resources to deal with the sensory world. Heart brain synchronization is thought to improve when subjects focus their attention on their pulse perception [14, 36, 43, 62],

Previous studies introduced the functioning of the blood pressure wave, which also acts as a synchronization signal and additional source of information sent to the brain which in turn has widespread effects throughout our entire cellular system [9, 11, 63]. This was observed during the repolarization, when the heart is relaxed at T5 and later time periods.

Negative emotion is evolutionarily more functional for survival and protection, resulting in increased activation in the limbic areas in response to the perception of threats in our environmental. In Figure 5(b), at T5, it seems that for negative self-talk, in temporal region, there is increased processing which interferes with afferent processing. Positive emotion, on the other hand, is more functionally suitable in brain areas that facilitate higher-level consciousness, such as planning, abstract thinking, and meaning formation. The signal from the heart appears to be less disrupted in its travel to the cortex during the resonant breathing condition and Heart Lock-in. When compared to breathing, HLI has the highest level of activation. This HBC technique is a heart focused type of meditation, which is thought to improve cerebral thickness and may broaden higher levels of consciousness, mental stability, and awareness [27, 64, 65].

Limitations

The present study has certain limitations that need to be acknowledged. Firstly, the sample size was relatively small, and the subjects were not experts in the field, which might have impacted the results. Secondly, the emotional stimuli used in the study were limited to a few categories, which may not represent the full spectrum of emotions. Therefore, future studies could benefit from exploring the oscillatory signatures associated with a wider range of emotional states.

5. Conclusion

This is the first study that analyzes the phasic HBC during HLI, breathing, and self-talk, simultaneously. The degree of variability in ECG and hence the amplitudes of HEPs, may be causing the brain to receive more afferent signals during HLI, which in turn modulates/increase brain functions and HBC. Self-talk interferes with neurocircuits, blocking the inflow of information across the cortex. Specifically, negative self-talk is more likely to disrupt the flow of afferent signals. Moreover, the neurophysiological implications propose that breathing helps to stabilize the parietal mid and back regions of the brain.

Credit Author Statement

Ayesha Ikhlaq, Rollin McCarty, Danijela Debelic, Muhammad Abul Hasan, Saeed Ahmed Buzdar: Conceptualization, Methodology, Investigation, Software, Data Curation, Writing – Original. Mike Atkinson, Normen Schack, Thomas Feiner, Muhammad Danish Mujib, Ahmad Zahid Rao: Formal analysis, Writing – Review & Editing, Visualization, Validation. Saeed Ahmed Buzdar, Mehrun Nisa, Mamoona Aslam, Muhammad Usman Mustafa, Sana Salahuddin: Project administration, Supervision, Funding acquisition.

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