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The consequences of eye tracking on brain and heart coherence

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Abstract

When the eye uses the brain and heart, the cardiovascular and nervous systems integrate and interact. Because changes in retinal microcirculation are independent predictors of cardiovascular events, the eye serves as a "display" to the cardiovascular system and brain. The eye, which has two circulatory systems and a rich vascular supply, is a prime candidate for this study and benefits from early damage to the target organ. Eye movements performed during the visual search pose a challenge in identifying critical points in the eye scene. Because it uses different brain pathways and relates to the cardiac cycle, humans' ability to spot anomalies under challenging circumstances means they are always needed for visual search. ECG (electrocardiogram), electroencephalogram (EEG), and eye tracking can improve visual search training and attention-tracking performance. EEG data can also be analyzed in real time using eye-tracking technology. Previous work has discussed the EEG or ECG concerning attraction during visual search. The eyeball's movement combined with the ECG in the previous investigation and introduced large electroencephalographic (EEG) artifacts. This assessment aims to (a) identify brain–heart coherent features influenced by the visual search task and (b) discover the behavior of EEG frequency bands and heart rate variability (HRV) features. EEG and ECG were used to analyze and predict inattention in individuals during a visual search task. The EEG determines human brain function and considers to detect the variability in the EEG frequency band. The work proposed a visual search task with EEG and ECG analysis. Five participants recorded EEG and ECG recordings in three different scenarios: rest, gaze tracking, and normal. Statistical evaluation was used to compare EEG and ECG characteristics and Pearson's correlation was employed for statistical analysis. Statistical ANOVA analysis revealed statistically significant ($p > 0.05$) differences between theta (F3) and alpha (F3) EEG and ECG features, as well as between theta (F4) and alpha (F4) EEG and ECG features. Additionally, alpha (F3) and theta (F3) were significant in the heart rate variability index (rMSSD), which monitored activity under eye tracking. There was also a significant difference between alpha (F3) and mean HR. Pearson's correlation between ECG and EEG shows that theta (O1) and alpha (O1) correlate with LF/HF and alpha (F3) and theta (F3) with rMSSD. Theta (F3) and mean heart rate were also correlated. Observing the above ECG and EEG characteristics can improve and control treatment options for conditions like neurovascular instability (NCVI), characterized by age-related changes in blood pressure and increased cerebral and cardiac leukoaraiosis.

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1 Introduction

Target hunting is something that usually comes up daily in visual exploration. Fixation occurs when the eye focuses on a visual target [1]. The complex target detection during visual search is carried out without moving the eyes and head because a lower percentage of visible events allows progress toward clear visual understanding when only one image is occupied.

Eye tracking is a method for determining eye movements [1]. The retina has dense nerves and a fovea (high visual acuity) [2]. When a person looks at something, the eye's lens focuses light onto the fovea, and the person switches eyes to "aim" the lens and fovea [2].

By analyzing these changes in the eye, scientists can use eye-tracking technology to gain valuable insights into human behaviors, such as visual perception and attention [3].

The relationship between the brain and heart manifests through four main pathways: neurological (nerve impulses), biochemical (hormones and neurotransmitters), biophysical (pressure waves), and energetic (interaction of electromagnetic fields) [4]. However, communication usually occurs in eye tracking for different human states [5].

The four brain areas are the occipital, temporal, parietal, and frontal lobes [6]. The frontal lobe controls complex functions and voluntary movements [7], whereas the parietal lobe processes taste, temperature, action, and touch [8].

The lobe responsible for vision is the occipital lobe. [9]. Eye movement control or eye movement tracking in the cerebral cortex affects the occipital lobe [10]. Heart rate variability (HRV) refers to a physiologic heart abnormality dominated by the autonomic nervous system (ANS) [11]. HRV excerpt as of ECG with QRS complex [12]. Eye movements have been associated with ECG in previous studies [13].

EEG is a convenient method for analyzing the cortical response. Furthermore, EEG offers valuable evidence to study the irregularity of mental health status [14]. EEG can also be used in neurofeedback [15]. A 10–20 system is the most frequently used electrode localization approach for gathering EEG data and is used in most currently available databases [16]. Each electrode place is represented with a sign in this system to categorize the reading lobe or part of the brain [17]. Even digits reflect the brain's right hemisphere, and odd digits reflect the left hemisphere. For instance, the electrodes F2 and F3 correspond to the right and left frontal lobes of the brain, respectively [18].

The amplitude of the EEG signal is approximately one microvolt. Raw EEG, time series data, is converted to frequency data and classified into frequency ranges, and theta and alpha were evaluated in this study [19].

Eye movements trigger large electroencephalographic (EEG) artifacts [20]. Combining eye tracking with EEG and other neurophysiological recording devices like ECG would give the best eye-tracking analysis. Additionally, combining multiple biological signals helps compare EEG, peripheral physiology, and eye-related measurements to assess mental states [21]. This study targeted the brain and heart, as illustrated in Fig. 1's flow chart.

The right and left alpha activity variation is mentioned as frontal alpha asymmetry (FAA) [22]. It is considered an indicator of affect states and characteristics, as well as affect regulation in the waking state [23]. The FAA was calculated in a frontal position
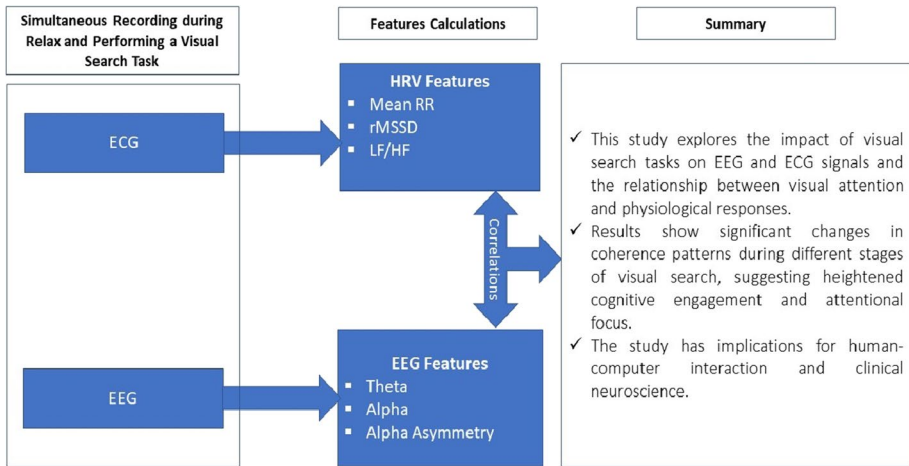
Fig. 1 Flow Chart of Study

(F4-F3). The study selected 10–20 electrode placements to target the frontal and occipital lobes, as shown in Fig. 2.

Many studies have focused on EEG eye tracking. One of the essential works in this field shows the behavior of eye movements and aims to better understand eye movement artifacts and brain–heart interactions, as well as the implications of eye-tracking performance [20]. The purported ICA method includes tools for detecting and correcting artifact components associated with eye movements [20]. The EEG measurements were used in various techniques to demonstrate the effect of video advertising on consumer attention. The other study, for example, investigated how the alpha and theta bands of the EEG changed while watching happy and unpleasant video ads. They found that viewing pleasant (versus unfavorable) video ads resulted in unequal increases in theta and alpha activity [24].

Another study used a visual distraction to collect EEG and HRV data to show how narrative video stimuli affect preferences in a large audience [25]. Sixteen people predicted the effectiveness of video ads shown during the 2014 Super Bowl and measured the HRV

Fig. 2 The 10–20 Electrode Placements in this Study and selected to Target the Frontal and Occipital lobes
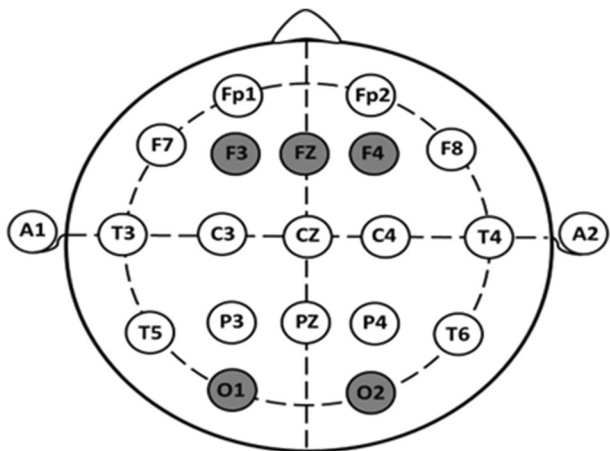
(Root Mean Square of Successive Differences, rMMSD) function [25]. Metric related to HRV [25].

This article examined memory impairment during video advertising as another strategy [26]. The authors proposed a metric based on EEG signals' total theta band power [26]. The authors also presented an impression index that combines indicators of memory and attention. This indicator appears when viewers watch video advertisements while their EEG activity is monitored [27]. However, this study uses EEG and ECG as part of the device.

EEG and ECG capabilities can be enhanced to reveal previously unrecognized connections between the neurological and cardiovascular systems and eye tracking. Subjects met three conditions: calm, performing the eye-tracking task, and normality during the visual search task (divided attention) using eye-tracking [28].

This evaluation intends to uncover brain–heart coherent aspects driven by the visual search task and learn how heart rate variability (HRV) features and EEG frequency bands behave.

2 Methods

This article recommends using MATLAB to simultaneously calculate EEG and ECG parameters in three sessions (rest, eye-tracking activity, and normal), each lasting five minutes. Eye tracking is used during attention sessions to perform a subject's visual search task [28, 29].

2.1 Subjects

Five right-handers provided a total of five EEG recordings. The biometric data in Table 1 show that there were five men. A consent form was completed and collected from each patient. Many questions have been raised about their privacy (Medical Expenditure Panel Survey (MEPs')). An Institutional Review Board Office has approved all testing using human protocols and registered sites.

2.2 Data analysis

The ECG noise was ilmenite by low–high pass filters set at 0.5 Hz and 70 Hz. Bandpass filtering was used to remove artifacts at (1–35 Hz).

EEG data collecting was performed with the DSI-24. EEG signals were recorded with Streamer software (DSI) with a sampling rate of 300 Hz. The EEG features extraction is

Table 1 Subject Information

Information	Data
Gender	Male: 5
Age	29.6 ± 2.1
Weight	102 ± 30 kg
Hight	168 ± 3.5 Cm
BMI	35 ± 9 kg/m^2

Fig. 3 PSD for a Relaxation Session
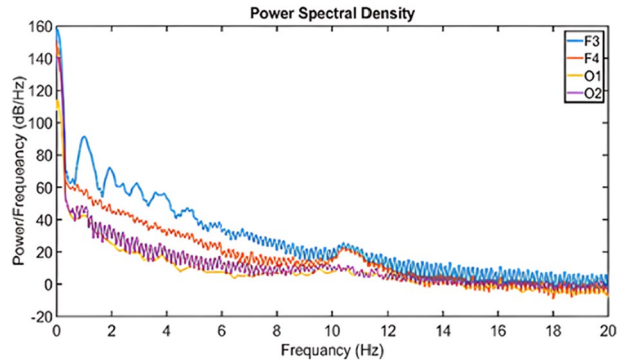
Fig. 4 PSD for Eye Tracking Task
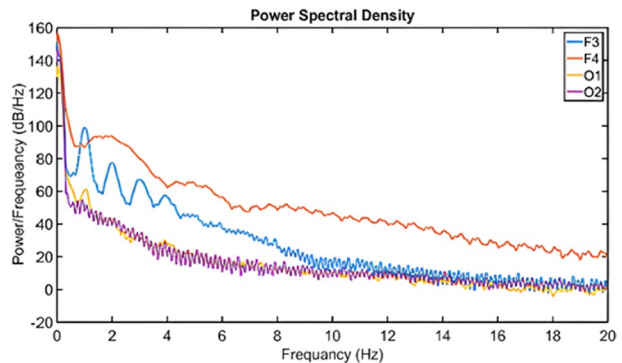
Alpha Power (AP), Theta Power (TP), and Alpha Asymmetry (AA), while HRV features extraction are rMSSD, Mean RR, and LF/HF.

O1 and O2 were selected for EEG signal analysis. The ECG was recorded with a Bio Radio 150 under three conditions at a rate of 960 samples/s. Bio Radio is a 12-lead system where the device collects ECG data. The HRV electrodes were placed according to Einthoven's thoracic placement principles.

2.3 Statistical evaluation

Pearson correlation and One-way ANOVA were applied as a statistical approach. For all statistical tests, the significance level was ($p \leq 0.05$).

3 Results

The biometric data for all Saudi subjects appear in Table 1. All subjects were right-handed, non-smokers, and ate before the experiment. They also exercise for 1–3 days a week, watch television 1–4 days per week, use their mobile phones (3.0 ± 3.1) hours per week, and study for 1–3 h per day. Their number of siblings is (5.6 ± 0.6). The last question at the end was on a scale of 1 to 10 and asked, "How good is your vision at tracking eye movements?" The answer was (6 ± 0.7). The power spectral density (PSD) intended for frontal (F3, F4) and occipital (O1, O2) electrodes are shown in Figs. 3, 4, and 5.

Fig. 5 PSD for Normalcy Session
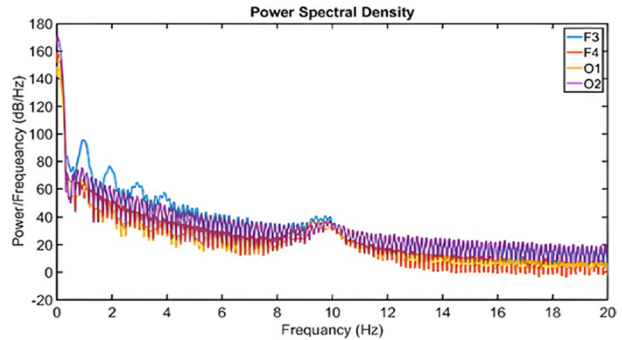
Table 2 EEG Features calculation an electrode F3

Feature	Rest	Eye Tracking	Normalcy
Theta	8.0±0.3	9.0±0	8.0±0.1
Alpha	10.0±0.3	11.0±0	10.0±0.2

Table 3 EEG Features calculation an electrode F4

Feature	Rest	Eye Tracking	Normalcy
Theta	8.0±0.2	8.5±0.2	8.0±0.2
Alpha	10.5±0.2	11.0±0.2	10.0±0.2

Table 4 EEG Features calculation an electrode O1

Feature	Rest	Eye Tracking	Normalcy
Theta	6.0±1.3	5.0±1.3	4.0±1.4
Alpha	8.0±1.7	7.0±1.6	6.0±1.8

Table 5 EEG Features calculation an electrode O2

Feature	Rest	Eye Tracking	Normalcy
Theta	6.3±1.0	6±1.3	6.3±1.1
Alpha	8.0±1.3	7.5±1.7	8.0±1.5

Tables 1, 2, 3, 4 and 5 show the approximation for two frequency bands, alpha, and theta, during three recording periods. F3, F4, O1, and O2 electrodes were used for theta and alpha.

Table 6 shows the AAF calculation across alpha frequency bands, and Table 7 shows the analysis of HRV features

The theta and alpha frequency bands change in three sessions, as shown in Figs. 6 and 7.

Theta (F3) and alpha (F3) EEG and ECG features, as well as theta (F4) and alpha (F4) EEG and ECG features, showed statistically significant differences ($p = 0.00001$). Additionally, $p = 0.00005$ separates theta F4 from alpha F4. The rMSSD under-eye

Table 6 EEG Features calculation Alpha(F3/F4)

Feature	Rest	Eye Tracking	Normalcy
Alpha Asymmetry	0.01 ± 0.01	-0.01 ± 0.01	-0.003 ± 0.004

Table 7 ECG Features calculation

Feature	Rest	Eye Tracking	Normalcy
Mean RR	800 ± 59	790 ± 53	767 ± 57
rMSSD	100 ± 20	103 ± 12	102 ± 7
LF/HF	1.7 ± 0.4	1.9 ± 0.4	1.1 ± 0.2

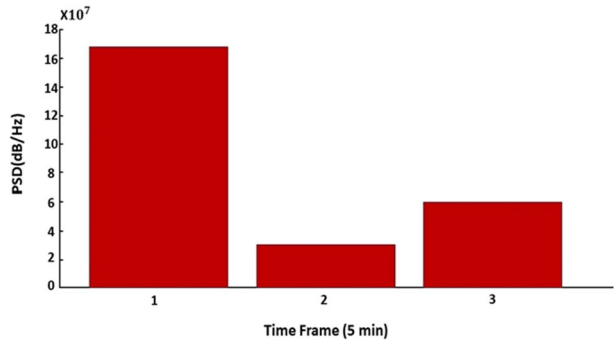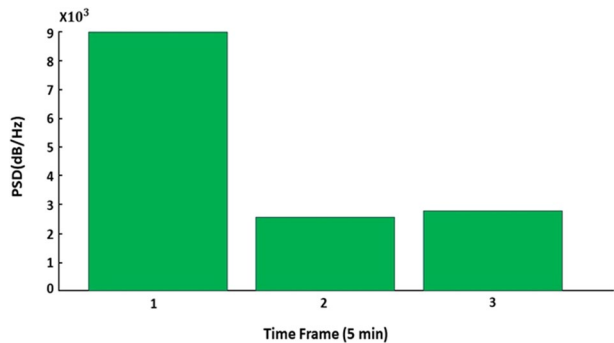**Fig. 6** A Bar Graph of Theta Band in three Conditions

Fig. 7 A Bar Graph of Alpha Band in three Conditions

track task results in statistically significant correlations between the alpha F3 ($p = 0.03$) and theta F3 ($p = 0.001$) responses. Furthermore, there was a significant correlation ($p = 0.03$) between mean HR and alpha F3. The correlation between ECG and EEG shows that theta O1 ($r = 0.3$) and alpha O1 ($r = 0.3$) were correlated with LF/HF, respectively. Alpha F3 and theta F3 had an ($r = 0.6$) and ($r = 0.8$) correlation with rMSSD, respectively. Besides that, theta F3 and mean HR were correlated ($r = 0.4$).

4 Discussion

This study used biomedical sensors to assess the implementation of EEG and ECG signals in parallel. The zone of influence of the occipital and frontal brain was recorded by visual search [9, 10]. Alpha and theta detect attention in alpha frontal asymmetry [24]. Alpha, theta, and alpha asymmetries were EEG features, while mean HF, rMSSD, and BF/HF were ECG features in this study.

Biometric results indicate the excessive use of electronic screens today, leading to vision problems and reducing the scope of visual searches [30]. Using eye-tracking analysis, the discovery of features of the brain and heart can improve the diagnosis of a range of vision-searching problems [31].

Figure 3 shows an increase in alpha wave (8–12 Hz) during a relaxation session, while Fig. 4 shows a decrease in alpha wave after a visual search task. Figure 5, the alpha wave begins to return to normal. Few reports of lateralized alpha activity after target emergence [32]. Theta wave power (4—8 Hz) shows the increase in Fig. 4. F3 and F4 have a huge impact compared to O1 and O2. The explanation is that the eye first recognizes the object and then goes through the brain to the occipital lobe. Nerve impulses from the retina move through the optic nerve to the frontal lobe. The optic nerve, optic chiasm, visual tract, optic radiation, and visual cortex connect to the occipital lobes via the frontal visual pathways [33].

In Tables 2 and 3, Theta increases in F3 and then decreases; hence the F4 electrodes decrease and behave differently in O1 and O2. This result is similar to the previous one, showing an increase in theta during visual search [34]. Human psychophysics also suggests that theta plays a role in visual search attention. More research is required to fully comprehend theta and the visual search domains [34]. The alpha wave has a similar mindset in three sessions. Alpha waves during visual searching are reduced, as described in this article [35]. The alpha asymmetry shows negative values in the eye-tracking session, suggesting that the left brain is more influenced by the alpha asymmetry in this study [36].

During visual searching, the frontal-occipital lobes are active, and the "memory-attentional pattern" includes one or additional target or objects [37, 38]. Additionally, anterior cingulate/pre-SMA, the medial IPS, and FEF are active through visual search [39, 40]. Figures 3, 4, 5, 6 and 7 and Tables 1, 2, 3, 4 and 5 show that alpha waves are associated with relaxation, eye tracking, and normalcy. The decrease in alpha waves is clearly shown in Fig. 3. When alpha was found to decrease during non-relaxation sessions, alpha asymmetry (AAF) diminished at electrodes F3 and F4 and remained stable. Table 7 shows that ECG calculations increase in eye tracking sessions followed by a decrease in normal sessions in LF/HF and rMSSD. This finding indicates that the likelihood loop is active during visual searches [40].

Figures 6 and 7 show that theta power substantially affects gaze tracking more than alpha power. Conversely, theta wave was associated with eye movements [41]. Heart Rate Variability Index (RMSSD) results show that an increase in RMSSD (presumably reflecting a slower heart rate) is associated with a decrease in gaze pattern deviation [25]. In addition, high LF/HF ratio levels specify the supremacy of sympathetic activity, which occurs when the subject behaves as fight or flight [42].

According to the statistical analyses, alpha and theta in the frontal area show significant results. Five correlations were found between relaxation sessions and gaze tracking in EEG and ECG functions. Correlation between EEG and ECG shows that theta and alpha in lead O1 correlate with LF/HF, while alpha and theta in lead F3 are associated with rMSSD.

The brain immediately monitors the parasympathetic and sympathetic areas of the ANS. As a result, these findings lend credence to the brain–heart connection (neuroradiology) [43].

Neuroradiologists have investigated psychophysiology extensively, which explains the anatomy and function of the heart's internal nervous system and its connections with the brain [43]. It is recognized that the autonomic nervous system's efferent pathways participate in heart management in terms of heart-brain communication [44].

The fact that most vagus fibers are afferent is less well-known. The heart (and cardio-vascular system) is the organ with the most ascending neural pathways [45]. This happens when the heart sends more data to the brain than the brain sends out to the heart [46, 47].

Data collected from EEG and ECG may improve the detection and identification of cognitive attention compared to data gathered from EEG or ECG alone. The limitation of this article was the number of participants. The main interest of this study is to monitor the evolution of treatment to improve vision recovery. Eye tracking, ECG, and EEG variables are possible sources of information to recognize attention.

5 Conclusion

This study explores the potential synergies between data obtained from both EEG and ECG in enhancing the detection and identification of cognitive attention, surpassing the individual contributions of EEG or ECG alone. Despite the promising implications, it is crucial to acknowledge a limitation in the study related to the relatively small number of participants. The primary focus of this research revolves around monitoring the progression of treatment to enhance vision recovery. In pursuit of this goal, various variables such as eye tracking, ECG, and EEG are considered potential sources of information for recognizing attention patterns.

The study's results reveal a task-dependent modulation of coherence between EEG and ECG signals specifically during visual search tasks. This nuanced understanding sheds light on the intricate neural-cardiac interactions that underlie attentional processes. By elucidating the dynamic nature of cognitive and physiological coupling, these findings contribute valuable insights to our comprehension of attentional mechanisms. Beyond the realms of theoretical understanding, the implications extend to practical applications, especially in the development of attention-aware technologies and interventions tailored for individuals with attention-related disorders. This comprehensive approach not only advances our knowledge of cognitive attention but also holds promise for the refinement of targeted strategies aimed at improving attentional capabilities in clinical and technological contexts.

Data availability The data used in this study are available upon request.

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