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Effects of Physical and Psychological Stress on Cardiac Function a Brain Activity: An ECG-EEG Correlation Study

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Abstract

This study used ECG-EEG correlation analysis to examine how physical and psychological stress affects the heart and brain. Controlled stress-inducing activities included rigorous physical exertion and difficult mental demands. ECG and EEG signals were recorded during stressful tasks. The study found diverse physiological and brain responses to physical and mental stress. Intense exercise caused heart arousal and sympathetic activation in the participants. Heart rate, blood pressure, and ECG waveform characteristics rose. An electroencephalograph (EEG) showed increased beta and gamma band activity, indicating cognitive engagement and attentional concentration.Psychological stress tests, which involve cognitive issues and mental stress, caused varied heart and brain responses. ECG-derived emotional regulation and autonomic control indices and heart rate variability increased. Alpha and theta band activity in the patient's EEG showed cognitive and emotional changes.The study also showed significant relationships between cardiac and brain measures, revealing how stress affects the cardiovascular and central neurological systems. Some ECG characteristics correlated with EEG frequency bands, suggesting a link between heart activity and mental oscillations.

Keywords Physical Stress, Psychological Stress, Cardiac Function and Brain Activity.

Introduction

Further study is needed to fully understand the intricate relationship between the heart and the brain. There is no denying the connection between the brain and the heart, which is why neurocardiology is devoted to studying their reciprocal relationship. Both the heart and the brain can be affected by one another's activities. Multiple lines of evidence point to the brain's significance in arrhythmia, cardiac arrest, and other heart diseases.

It has long been assumed that the brain commands the heart via the central autonomic network, establishing a hierarchical relationship between the two. The brain, however, develops after the heart has begun beating. It is not necessary for a transplanted heart to be connected to the recipient's nervous system for it to continue beating. Because of this, the widely held view that the brain merely controls the heart has to be re-examined. Several investigations under various physiologic states and situations have been undertaken to learn more about the connection between brain signal complexity and heart activity. Electrocardiography (ECG) and electroencephalography (EEG) data acquisition is the standard method for accomplishing this.

Neurons can be thought of as the building blocks of the brain and nervous system. They regulate the body's motor, sensory, and endocrine impulses. These neurons generate observable electrical events during intraneural communication by virtue of the kinetics of ionic transport. EEG takes advantage of these electrical processes to provide a diagnostic assessment of the brain. An EEG process involves recording waves at a variety of frequencies. The production of delta waves, which can range in frequency from 1 to 3.99 hertz, is a side effect of hyperventilation. The brain naturally creates theta waves, which range in frequency from 4-7.99 Hz, while it is in a drowsy or sleeping state. Alpha waves, which can have a frequency range anywhere from 8-12.99 Hz, are thought to be responsible for the opening of one's eyes. In adults, the shift from wakefulness to sleepiness is accompanied by Beta waves, which have a frequency range that is higher than 13 hertz. However, the electrocardiogram, often known as an ECG, is a device that does not involve any invasive procedures and is frequently utilized in clinical settings as the primary tool to investigate the heart. By picking up electrical activity on the skin caused by cardiac activation and repolarization, it provides a visual picture of heart processes.

There have been studies analyzing the connection between heart and brain functions in a variety of physiological and psychological circumstances by taking simultaneous EEG and ECG readings. This includes brain activity while at rest, which may give a holistic view of brain operation. Brain rhythms and cardiac interactions follow a common pattern throughout sleep, according to research conducted by Bartsch, Ivanov, Lin, and Liu. A study looking at the benefits of meditation also discovered a direct correlation between heart rate and EEG

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alpha activations. Researchers Ahn et al. captured and analyzed respondents' multimodal EEG, ECG, and Electrooculogram (EOG) as they participated in driving simulation. It helped them identify the neuro-physiological characteristics that differentiate drivers with high and low fatigue concerns. In a separate investigation, Chiu et al. used mathematical models to compare ECG-measured HRV to EEG data during cardiac catheterization and coronary artery intervention. Researchers found that measuring heart rate allowed them to anticipate how a person's brain's electrical activity would respond to stress. In addition, Lin et al. analyzed the relationships between the complexity of brain and cardiac electrical activity using a multiscale entropy analysis, gathering data from 87 individuals via 24-hour electrocardiogram (ECG) and 19-channel eye-closed regular electroencephalogram (EEG) observations. Although results demonstrated a correlation, more investigation is needed before it can be concluded that the central autonomic network is responsible for the observed heart-brain correlations.

The purpose of simultaneously recording ECG and EEG readings during physical and psychological stress is to establish a correlation between heart function and brain activity. In addition, the implications of the increased heart rate need to be investigated, and this must be done independently of whether a certain brainwave is predominating or if other stimuli were involved in the increase in BPM.

2. Biomedical Sensors

A. Electrocardiogram

Electrocardiograms, more often referred to by its acronym ECGs, are diagnostic tests that record the electrical activity of the heart. It is a method that does not involve any intrusive techniques, yet it nevertheless gives useful information regarding the rhythm, rate, and overall cardiac function of the patient's heart. It is routine practice to do an electrocardiogram (ECG) in order to evaluate the electrical conduction system of the heart and identify any abnormalities or disruptions. During an electrocardiogram, the patient will have electrodes attached to their chest, arms, and legs at several predetermined spots. Electrodes like this are used to pick up on the minute electrical impulses that are produced by the beating of the heart as it contracts and relaxes. After that, the electrical activity is increased and shown on the ECG monitor as a graph or a sequence of waves.

B. Electroencephalogram

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Electroencephalograms, more commonly known as EEGs, are non-invasive diagnostic tools that assess and record the electrical activity of the brain. It is an extremely helpful diagnostic tool that may test brain function and identify anomalies in the activity of the brain. The electroencephalogram (EEG) is a tool that can assist in the diagnosis of a variety of neurological diseases since it can reveal the brain's underlying electrical patterns and rhythms. An electroencephalogram (EEG) involves attaching electrodes to strategic points on the scalp by means of a specialized conductive gel or paste. These electrodes are able to both detect and enhance the minute electrical signals that are generated by the neurons in the brain. The electrodes are positioned in such a way as to catch the electrical activity emanating from a variety of different parts of the brain.

3. Signal Processing

In order to perform analysis and interpretation, electrocardiograms and electroencephalograms substantially rely on the processing of signals. Electrocardiogram (ECG) and electroencephalogram (EEG) sensors are used to increase the accuracy of measurements and to acquire information that is not easily accessible from the signal via eye inspection. This is the case in spite of the fact that ECG and EEG readings might be periodically thrown off by a variety of various sorts of noise that arise as a result of another physiological activity taking place within the body. The sensors all employ the same basic collection of algorithmic building pieces in their operation.

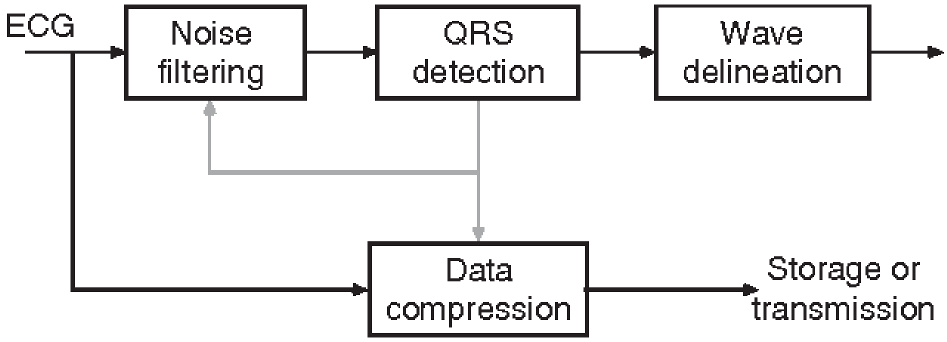

Figure 1 – Algorithm for basic ECG signal processing

Figure 1 depicts an example algorithm for basic ECG signal processing signal. An electrocardiogram (ECG) can be used to read heartbeats and measure the amplitude and length of the waves once the signal has been conditioned to remove various types of noise and artifacts. The penultimate step before data may be efficiently stored or sent is compression. In theory, the same method can be applied to EEG analysis.

4. Methodology

1) ECG Sensor

ECG suction cups, the PASPORT EKG Sensor, and the PASPORT data logger are the necessary components and pieces of equipment for the ECG sensor. Additionally, the ECG sensor requires the PASPORT data logger. The PASPORT EKG, which was manufactured by PASCO solely for the purpose of being used in educational settings, was the electrocardiogram (ECG) sensor that was used by the researchers. It has a sampling rate of 200 samples per second, a heart rate range that runs from 47 to 250 beats per minute, and a resolution of 1 beat per minute for the heart rate readings it displays. It has a measuring resolution of 4.5 v and a voltage range that goes from 0 mV to 4.5 mV when it comes to voltage measurements.

2) EEG Sensor

You will require the following materials in order to construct an electroencephalogram (EEG) sensor: a BIOPAC electrode lead set, some BIOPAC disposable vinyl electrodes, some BIOPAC electrode gel, an abrasive pad, and some rubbing alcohol. An electroencephalogram (EEG) instrument known as an EEG sensor, manufactured by BIOPAC Systems, Inc., was utilized by the researchers. Using this apparatus, the researchers investigated montages consisting of many channels. Because spectral analysis and real-time EEG filtering are included in this device, the researchers are able to analyze multi-channel montages specifically for alpha, beta, delta, and theta wave activity. This is made possible by the presence of these two features.

B. Preparation for ECG and EEG Measurements

The ECG sensor's connection was initially linked to a free PASPORT interface port so that configuration could commence. Then, alcohol was massaged into the subject's skin. Figure 2 shows how the ECG's suction cups were placed on the Chest at Different Places all at the skin.Following that, we reorganized the cables in such a way that they could dangle freely without putting any pressure on the suction cups.

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Figure 2 – Suction caps

Despite the fact that the computer is powered on and ready to go, the BIOPAC MP3X is not now active. After that, the BIOPAC MP3X was provided with power, and the electrode lead (SS21) was connected to channel 1.

Electrodes were placed in several parts of the subject's skull. The electrodes can be kept in place with the use of a head cap. The next step is for the participant to settle into a comfortable position in front of the computer. The student lab program at BIOPAC didn't begin until after that. Then, the user clicked the "calibrate" button in the interface's upper left corner to adjust the sensor's settings. Repeat the procedure and examine the recorded measurements for clues as to what went wrong. If the volunteer agrees to participate in the study, they will be included in it. In the event that this is not the case, the electrode connection will be examined, and the process of calibrating the device will be resumed. In the event that the results of the two calibration measurements do not coincide, the procedure will be repeated until such time as they do.

C. Investigating the Effects of Physical Stress on the Activity of the Brain and the Cardiac Function

Before taking his ECG and EEG readings, the subject was asked to find a posture on a chair that was most comfortable for him. The next step is to have the patient jog in place for two minutes. After he is done with the exercise, we take his electrocardiogram (ECG) and electroencephalogram (EEG) readings and then take them again after 30 seconds of rest. After collecting their data, the researchers went on to the analysis phase.

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D. Examining the Effects of Emotional Stress on the Workings of the Heart and the Activity of the Brain

Participants were first asked if they were undergoing treatment for any medical conditions, such as heart problems, and then if they were able to watch a disturbing video clip. After passing security, they were given some downtime to relax, listen to a suspenseful video while wearing headphones. Subjects' heart rates and brain electrical activity were recorded during the viewing. The data was analyzed by the researchers after the measurements were taken.

5. Results and Discussions

A. ECG Measurements and Analysis

Each participant was asked to do two things for the study: (1) jog in place for two minutes, and (2) watch a clip from a suspense film that featured a jump scare. The researchers kept track of their data for each task during this period and compared it to the initial readings. Table 1 shows that, as expected, individuals' heart rates increased significantly after the 2-minute jog but declined only marginally after the 30-second recovery period. The heart is responsible for continuously pumping blood throughout the body, delivering oxygen and nutrients that are necessary for the health and function of all of the body's tissues and organs. In this study, it was shown that a rise in heart rate after running was indicative of a need for a rise in the body's requirements, and that this rise gradually dipped back down to resting levels as the body recovered from the strenuous exercise (see Figure 3).

Table 1 – Comparison of pre- and post-exercise heart rates

Subject	Before	After	Recover
1	70	120	100
2	85	135	115
3	75	130	105
4	70	125	100
5	95	155	125
6	80	140	120
7	75	130	105
8	90	150	130
Average	79	136	111

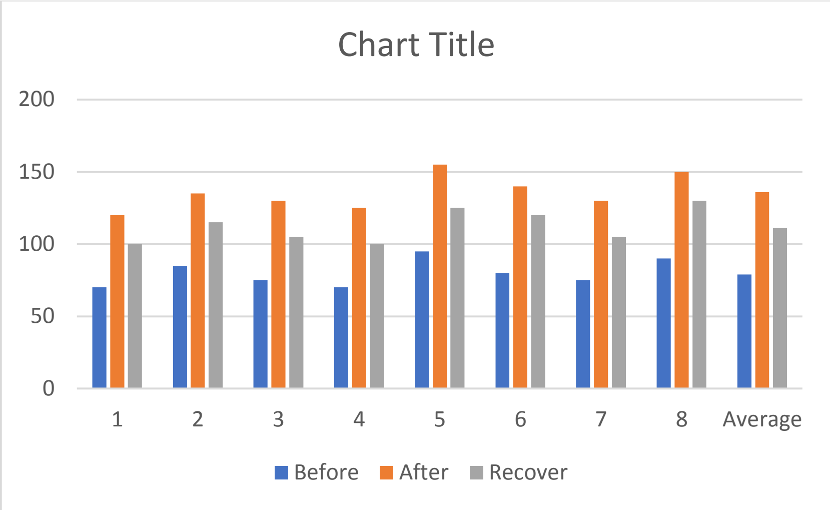

Figure 3 – Heart rate variability before, during, and after exercise, with a 30-second recovery interval shown graphically.

After that, everyone saw a snippet from a dramatic video that ended with a sudden, startling scare. The researchers were unable to record the real-time figures prior to the development of jump fright because of the sensitivity of the ECG sensor. However, after the danger had passed, they were able to successfully take it. The physiological connection between frightening experiences and a faster heart rate as a result of a jump fright is laid forth in table 2.

Table 2 – Subjective heart rates were measured before and after they watched a suspenseful video

Subject	Before	After
1	70	97
2	85	118
3	75	105
4	70	98
5	95	133
6	80	116
7	75	108
8	90	122
Average	79	113

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B. EEG Analysis

During the course of the experiment, there were two distinct phases in which recordings of the participants' brainwaves were made. During Experiment A, which consisted of jogging in place for two minutes, immediately followed by a jump scare, the subject's electrical activity was recorded before, during, and for thirty seconds after the experiment. Experiment B involved monitoring the subject's electrical activity in real time as a terrifying movie was played in the background.

The standard deviations of the individuals' electrical activity that were measured while the experiment was being carried out are shown in Figure 4. This figure may be seen below. It is possible to derive each of the four values that are connected to the symbol sigma; these values are referred to as alpha, beta, delta, and theta.

Table 3 – Quantifying the mean and range of brain activity when running.

Rhythm	Pre-Exercise	Post-Exercise	Recovery
Alpha	0.35000	1.70000	0.90000
Beta	0.55000	1.55000	1.35000
Delta	0.60000	4.80000	2.40000
Theta	0.40000	2.40000	1.20000

The electrical activity of the participants throughout part A of the experiment is shown in Table 3, together with the mean and standard deviation of that activity's values. The values that were gathered during the experiment's pre-exercise phase will be used as the foundational values throughout the entire experiment's portion A. It has been shown that the highest level of electrical activity occurs immediately following physical exertion.

Table 4 – Variation after exercise minus return to baseline

Rhythm	Difference b/w pre and post-exercise	Difference b/w pre and post-recovery
Alpha	1.5	0.6
Beta	1.0	0.8
Delta	4.8	2.0
Theta	2.4	1.0

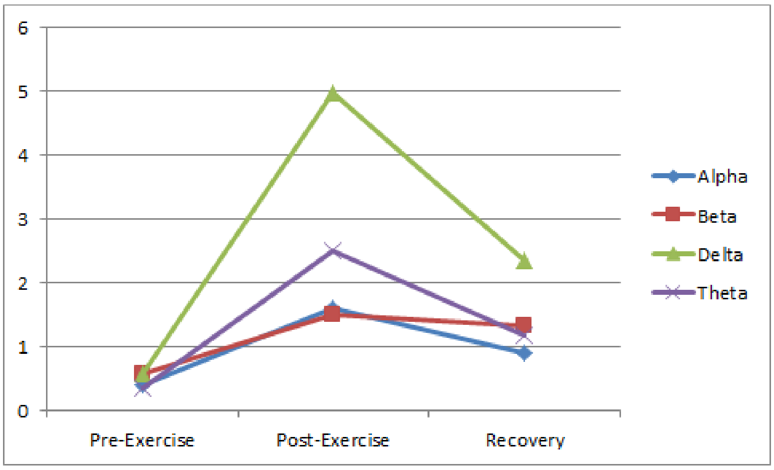

Figure 4 – Standard Error of the Mean (A) Graph Delta for green, Theta for violet, Alpha for blue, Beta for red

When one examines Table 4 and Figure 4, it becomes immediately apparent that the delta waves show the most significant departure from the baseline value. Delta waves are associated with the unconscious activities that take place inside the body, especially those ones that involve the circulatory and digestive systems. We are able to recall that in the first half of the experiment, the subject engaged in physical activity that led to an elevation in their cardiovascular function. In addition to this, it is believed that they are responsible for the disruption of the subject's ability to relax. As a result, there is a significant contrast between before and after exercise. Theta waves, which are typically detected while a person is asleep or daydreaming, are responsible for the difference that comes in second place after the highest difference. Therefore, these waves indicate that the mind is in a calm condition. It's possible that high levels indicate impulsive behavior.

Table 5 – Variability in brain activity while subjects watched suspenseful videos, normalized to a mean value

Rhythm	Pre-jump-scare	During jump-scare	Post-jump scare
Alpha	1.33496	7.2905	7.83957
Beta	1.44086	7.75024	6.87406
Delta	5.02274	22.87917	41.06976
Theta	1.76712	11.15714	15.17222

Table 5 shown the informationsduring the experiment's second phase (B). All of the viewer's electrical activity is monitored for the full duration of the scare-video. A jump scare is indicated by the term during, and its immediate aftermath is referred to as post-jump fear.

There is a peak in brain electrical activity right after a jump scare video. There was a sudden increase in electrical activity values.

Table 6 – The change from the control value that occurs during and after a jump scare

Rhythm	Difference between During jump-scare and Pre-jump-scare	Difference between During Post-scare and Pre-jump-scare
Alpha	5.95554	6.50461
Beta	6.30938	5.4332
Delta	17.85643	36.04702
Theta	9.39002	13.4051

The data shown in Table 6 reveals, in line with the conclusions we came to, that theta and delta waves predominated the other waves. On the other hand, the value of the alpha waves is the least significant of all of the waves. It is a widely held belief that the 'frequency bridge' between conscious and subconscious thinking is formed by the brain's alpha waves, which are assumed to be responsible for this function. When they are in a state that allows for relaxation and tranquillity, they are able to perform to the best of their abilities. Because of this, its value is at its lowest both during and after the jump-scare movie; this is because the participants are not in a tranquil condition during either of these periods. Because of this, its value is at its lowest both during and after the jump-scare movie. As a consequence of this, its worth is at an all-time low both during and after the jump-scare movie. The differences between the values of the lowest waves and those of the beta waves are hardly distinguishable to the naked eye. It is a term that refers to the state of consciousness, which can be demonstrated through actions such as deliberation, computation, reading, or speaking. The participants in the experiment are aware of their surroundings; but, during the experiment, they are not engaging in any of the activities that were previously described. They are only monitoring the situation; hence, the value of beta is neither at its lowest nor at its maximum possible point at this time. The ability to focus on one's work and complete activities associated with it is made possible by the presence of a suitable amount of beta waves, such as this one (which is in the intermediate range).

Table 7 – Brain activity frequency distributions on an average

Period	Frequency (Hz)
Pre-Exercise	0.84329
Post-Exercise	1.560313
Recovery	0.99714
Pre-Jump-scare	0.93071
During Jump-scare	1.91232
After Jump-scare	0.75054

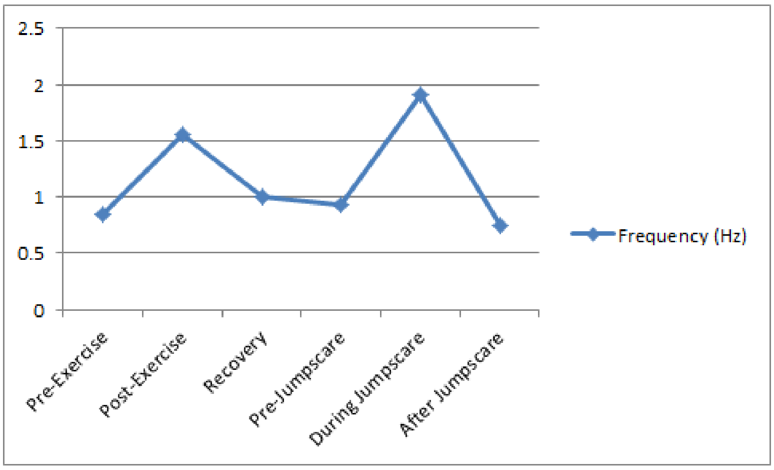

Figure 5 – Normal distribution plot

The frequencies of the EEG signal can be shown in table 7 and Figure 5 respectively. We can see that it reached its highest point immediately after the exercise as well as during the scary jump. This indicates that the brain is engaged in a significant amount of activity after the exercises. As a result, their efforts to stimulate the brain were successful. There is no difference in the frequencies of the various brain waves. After the activities, it is possible to see that the electrical activity has decreased, but despite this, it is still larger than the values at the beginning of the experiment.

When parts A and B are contrasted, it is clear that component B is superior in terms of its ability to boost the electrical activity in the brain. It's possible that this is due to the fact that the body is allowed to rest while viewing, in contrast to part A, which needs movement.

When the body has had sufficient rest, there is a better chance that the brain will be more receptive. Additionally, we are able to see that a startling occurrence (a good illustration of this is the jump fright) causes the electrical activity in the brain to reach its maximum value.

6. Conclusion

After the patients engaged in a variety of activities designed to stimulate them, the ECG and EEG recordings showed an increase in quality. It seems to imply that the pace of heartbeat and the activity of the brain have a discernible relationship with one another. The findings did not indicate any significant gender disparities between the two groups of people. Before beginning exercise, your heart rate should be between 65 and 68 beats per minute. After activity, it should be between 115 and 120 beats per minute. After people engage in various stimulating activities, the ECG and EEG recordings become more informative. It's strong evidence that the two are linked in some discernible way. No statistically significant differences between men and women were found. Before activity, heart rates are measured at 65–68, during exercise, at 115–120, and during recovery, at 98–99. The average rise in EEG after viewing the suspenseful clip was 43%, while the average increase in ECG was 68.35% after the jog and 15.78% during the recovery. When the delta wave predominates in the brain after a jog, it's a sign that the runner's brain is entering a resting state. Watching a suspenseful video clip, on the other hand, causes theta waves to predominate, indicating an impulsive activity in the body.

The complicated relationship between cardiac and cerebral functions is still up for debate. Although this paper achieved its goals with considerable success, the PASPORT EKG's great sensitivity to motion may have contributed to mistakes. The use of a motion sensor with less sensitivity in subsequent studies is warranted. Future studies may also employ a greater variety of tests designed to stimulate the heart and brain.

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