T.C.
BAHCESEHIR UNIVERSITY
GRADUATE SCHOOL
THE DEPARTMENT OF BIOMEDICAL ENGINEERING

INVESTIGATION OF THE EFFECTS OF REGULAR PHYSICAL ACTIVITY ON COGNITIVE ATTENTION USING EEG ANALYSIS

MASTER'S THESIS

MARYAM ANI

ISTANBUL 2024

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THESIS ADVISOR

THESIS ADVISOR: ASST. PROF. HAKAN SOLMAZ

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Institute Director

This thesis was read by us, quality and content as a master’s thesis has been seen and accepted as sufficient.

	Title/Name	**Institution**	**Signature**
Thesis Advisor's	Asst. Prof. Hakan SOLMAZ	Bahçeşehir University	
2nd Member	Asst. Prof. Engin BAYSOY	Bahçeşehir University	
3rd Member (Outside Institution)	Asst. Prof. Fatih KÜÇÜKTEZCAN	İTÜ	

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Name, Last Name: Maryam ANI

Signature:

ABSTRACT

INVESTIGATION OF THE EFFECTS OF REGULAR PHYSICAL ACTIVITY ON COGNITIVE ATTENTION USING EEG ANALYSIS

Maryam ANI
Master's Program in Biomedical Engineering
Supervisor: Asst. Prof. Hakan SOLMAZ

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The global reliance on technology and the contemporary way of life have significantly reduced human attention spans. The attention span of a golden fish might even be longer than the human attention span in some cases. This has incited scientists and researchers to investigate methods for augmenting the levels of attention exhibited by individuals. Various factors, including dietary and lifestyle choices, physical activity levels, sleep patterns, and hydration can influence attention. The purpose of this research was to examine the effects of regular physical activity on the attention levels of individuals through Stroop test performance evaluations combined with the analysis of EEG data measured throughout the tests. The participants were divided into two groups. Half of them were physically active people, while the rest were physically inactive people. The participants were healthy male subjects at the age of 18 to 30.

During the experiments, post-exercise heart rate measurements were taken, and EEG data were collected. EEG data were collected using a 32-channel wireless head cap system. EEG analysis following an exercise during the experiments has shown enhanced levels of attention for both physically active and inactive/nonactive group participants. Although the attention scores of physically active subjects were found to be greater than those of the nonactive participants, differences were found to be statistically nonsignificant following the exercise. Furthermore, there was no significant difference in the heart rate of subjects between the two groups before and after exercise. Alpha and Beta waves were particularly assessed during the study to see the effects of exercise on the changes in attention levels during the Stroop tests. The findings of the study are discussed in the results and conclusion parts of the thesis.

Key Words: Attention deficiency, EEG, Physical activity, Stroop test

ÖZ

DÜZENLİ FİZİKSEL AKTİVİTENİN BİLİŞSEL DİKKAT ÜZERİNDEKİ ETKİLERİNİN EEG ANALİZİYLE İNCELENMESİ

Maryam ANI
Biyomedikal Mühendisliği Yüksek Lisans Programı
Tez Danışmanı: Dr. Öğr. Üyesi Hakan SOLMAZ
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Küresel teknolojiye olan güven ve çağdaş yaşam tarzı, insanların dikkat sürelerini önemli ölçüde azaltmıştır. Bazı durumlarda Goldfish balığının dikkat süresinin dahi insan dikkat süresinden daha uzun olabileceği bilinmektedir. Bu durum, bilim insanlarını ve araştırmacıları bireylerin sergilediği dikkat seviyelerini artırmaya yönelik yöntemleri araştırmaya teşvik etmiştir. Beslenme ve yaşam tarzı seçimleri, fiziksel aktivite düzeyleri, uyku düzenleri ve hidrasyon gibi çeşitli faktörler dikkati etkileyebilir. Bu araştırmanın amacı, Stroop testi performansı değerlendirmeleri ile testler boyunca ölçülen EEG verilerinin analizi aracılığıyla bireylerin dikkat seviyelerinin düzenli fiziksel aktiviteden ne şekilde etkilenmiş olabileceğini incelemektir. Katılımcılar iki gruba ayrılmıştır. Bunların yarısı fiziksel olarak aktif kişilerken, geri kalanı fiziksel olarak aktif olmayan kişilerdir. Katılımcılar, 18-30 yaş aralığında sağlıklı erkek bireylerden seçilmiştir.

EEG verileri, 32 kanallı kablosuz başlık sistemini kullanarak toplanmıştır. Deneyler sırasında egzersiz sonrası kalp atış hızı ölçümleri yapılmış, EEG verileri toplanmıştır. EEG analizleri ile, hem fiziksel olarak aktif hem de aktif olmayan/grup katılımcılarının dikkat seviyelerinde artış gözlemlenmiştir. Fiziksel olarak aktif olan

katılımcıların egzersiz sonrası dikkat puanlarının aktif olmayan katılımcıların puanlarından daha yüksek olduğu ancak bu farkın istatistiksel olarak anlamlı bulunmadığı gözlemlenmiştir. Dahası, iki grup arasındaki deneklerin egzersiz öncesi ve sonrası kalp atış hızında anlamlı bir fark bulunmamıştır. Özellikle Alfa ve Beta dalgaları, Stroop testleri sırasında dikkat seviyelerindeki değişikliklerin egzersizin etkilerini görmek için değerlendirildi. Çalışmanın bulguları, tezin sonuç ve tartışma bölümlerinde tartışılmıştır.

Anahtar Kelimeler: Dikkat eksikliği, EEG, Fiziksel aktivite, Stroop testi

DEDICATION

I am incredibly grateful to my family, who have always supported me and encouraged me to pursue my goals. My parents, who were there for me both financially and emotionally, deserve my deepest gratitude. Your faith in me and desire for my happiness have always been clear to me. The people who have always believed in me and encouraged me to achieve my goals—my mom, who was the role model for me to follow and who inspired me to pursue a degree—as well as my dad and sisters.

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LIST OF ABBREVIATIONS

EEG	Electroencephalography
PA	Physical Activities
PE	Physical Exercise
HR	Heart Rate
AS	Attention Span
SCWT	Stroop Color and Word Test
ADHD	Attention-Deficit/Hyperactivity Disorder
EMG	Electromyography
ECG	Electrocardiography
APF	Alpha Peak Frequency
MVPA	Moderate-to-Vigorous Physical Activity
EF	Executive Functions
RHR	Resting Heart Rate
HRV	Heart Rate Variation
SAC	Standardized Assessment of Concussion
K-D test	King-Devick test
TBI	Traumatic Brain Injury
VO2	Oxygen Volume
RPE	Rating of Perceived Exertion
STE	Stroop Test Effect
ICA	Independent Component Analysis
EOG	Electrooculogram
SPSS	Statistical Package for the Social Sciences
TMT	Trial Making Test
ASR	Artifact Subspace Reconstruction
FIR	Finite Impulse Response
CAR	Common Average Reference
PSD	Power Spectrum Density

Chapter 1

Introduction

In this chapter, the theoretical framework and research problem of this research are introduced. It includes the research question, hypothesis, the study objectives and highlights the significance of the study.

1.1 Theoretical Framework

As a consequence of the impacts of modern life and technology, decreased attentiveness has been identified as one of the most common challenges we confront. It is expected that there will be variations in how the effect of brain signals and attention is assessed between individuals who engage in regular physical activity and those who do not, as determined by the concentration of brain waves during cognitive tests.

1.2 Problem Statement

In today's constantly connected world of social media, smartphones, and interruptions like hyperlinks embedded within everything you read, maintaining focus can be quite challenging. Recent studies have shed light on the decline in attention spans. It has been reported that the average attention span dropped from 12 seconds in the year 2000 to just eight seconds by 2013, which is even shorter than the nine-second attention span typically associated with a goldfish (Subramanian, 2018).

1.3 Purpose of the Study

This study aims to investigate the impact of regular exercise on the cognitive functions of individuals examining the brain waves among two groups, namely physically active and inactive. Stroop Color and Word Test (SCWT) was applied to the subjects before and after aerobic exercise, to explore the immediate and regular effect of exercise on attention levels.

1.4 Hypothesis of the Study

There exists a well-established correlation between exercise and alterations in brain function, including modifications in brain wave patterns and enhancements in attention. Researchers propose that regular exercise may induce changes in the brain's electrical activity, particularly within the alpha and beta brain wave frequencies (Hendrayana, Negara, Nuryadi, Gumilar & Lesyiana, 2020 ; Gutman et al., 2015).

Studies indicate that exercise can augment alpha and beta wave activity, suggesting a potential relaxing effect on the brain and an improvement in attentional focus (Hendrayana, Negara, Nuryadi, Gumilar & Lesyiana, 2020 ; Gutman et al., 2015). Additionally, investigations have revealed that exercise can elevate the production of neurotransmitters such as dopamine and serotonin, which play crucial roles in mood regulation, motivation, and attention (Basso & Suzuki, 2017).

The alterations in neurotransmitter levels induced by exercise may lead to enhanced attention, diminished anxiety, and heightened feelings of well-being. The primary inquiries addressed in this thesis are as follows:

1. Does physical activity have any impact on attention?
2. Does physical activity immediately affect attention and cognitive functioning?

1.5 Significance of the Study

In recent years, there has been a significant increase in the study of brain functioning, particularly within the fields of physical activity and sports sciences. Research has highlighted positive relationships between regular or intense physical activity in early life and various cognitive abilities, including attention, concentration, memory, working memory, cognitive flexibility, inhibitory control, and processing speed (Reigal et al., 2020).

With the advancement of technology and scientific knowledge, brain science has emerged as a crucial research field for exploring the mysteries of life. Research in this area focuses on understanding the structure and mechanisms of the brain, origins dating back to the 1960s. Over the past few decades, brain science has garnered consistent attention worldwide (Wan, Yang, Huang, Zeng & Liu, 2021).

Electroencephalography (EEG) serves as a tool for recording the electrical activity of the human brain. Essentially, it captures changes in the membrane potential inside the cell, which is relatively negative compared to the potential of the extracellular space (Kirschstein and Köhling, 2009). An EEG sensor is an electronic device designed to measure electrical signals generated by the brain. These sensors typically detect the fluctuating electrical signals produced by the collective activity of large groups of neurons near the brain's surface over a period of time. They sense small variations in the electrical current between the skin and the sensor electrode, amplifying this current, and applying any necessary filtering, such as a high-pass, low-pass, or band-pass filter (Kannathal, Rajendra, Acharya, Lim, and Sadasivan, 2005; Soufineyestani, Dowling, and Khan, 2020).

Brain signals are typically recorded using electrodes or channels placed on the scalp or, in some cases, directly on the cortex of the patient. These signals are then captured and processed by a computer interface. EEG signals are highly complex signals that contain a wealth of information about the functioning of the brain and might give information about any probable neurological disorder. Analyzing this signal presents significant challenges due to its complexity. EEG analysis is a valuable diagnostic tool, providing insights into brain health and identifying abnormalities in electrical brain activity (Shakshi & Jaswal, 2016).

In essence, EEG serves as a means to detect and indicate deviations from normal brain function, assisting in the diagnosis of brain damage, neurological disorders, and even brain death.

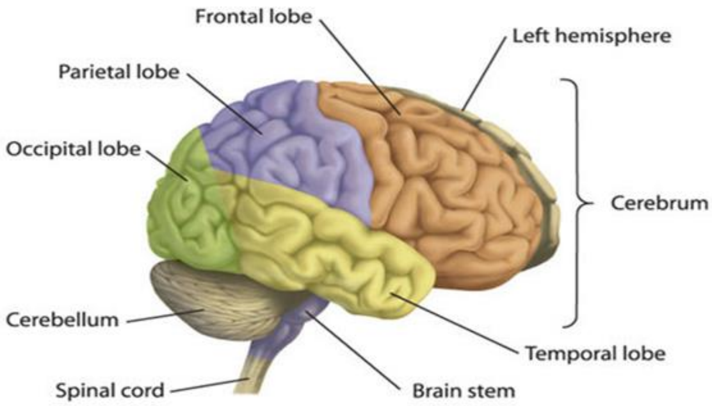


Figure 1. The brain parts (Duarte,2017).

Brainwaves are characterized by their frequency of pulsation, often with multiple patterns interacting simultaneously. The brain consists of two hemispheres, the left and right hemispheres. The left hemisphere is linear, logical, practical, and time-oriented, whereas the right hemisphere is nonlinear, abstract, creative, holistic, and nonlogical. Linear thinking, which is represented by the left hemisphere involves following step by step process to solve while nonlinear thinking, which is represented by the right hemisphere, has more flexibility and adaptation than linear thinking.

Delta waves, with a frequency ranging from 1 to 4 Hz, are associated with deep dreamless sleep, deep trance states, and the release of growth hormone by the pituitary gland. They play a role in self-healing processes and are prevalent during deep non-REM sleep stages (Aparnathi and Dwivedi, 2014; Jiang, Bian& Tia, 2019; Teplan, 2002). Brainwaves represent the electrical activity that occurs during neurological processes in the brain (Li, Chao & Zhang, 2019).

Theta waves range from 4 to 8 Hz and are linked to increased memory, creativity, imagery, and visualization. They facilitate free-flowing thought, future planning, and inspiration, and are associated with drowsiness, dreaming, and REM sleep states (Aparnathi and Dwivedi, 2014; Teplan, 2002).

Alpha waves oscillate at frequencies ranging from 8 to 13 Hz and are associated with a relaxed state of consciousness. Alpha waves signify a less arousal state and help to increase self/body awareness. They are present during meditation and deep relaxation (Aparnathi and Dwivedi, 2014; Teplan, 2002).

Beta waves operate at frequencies ranging from 13 to 30 Hz and represent the highest frequency brainwave activity predominantly found during wakefulness. They are associated with outward awareness, an engaged mind, heightened arousal, active perception, and evaluation of sensory data. Beta waves are also present during emotional states such as fear, anger, worry, hunger, and surprise. (Aparnathi and Dwivedi, 2014; Teplan, 2002)

Gamma waves are present all over the brain and they are a part of the EEG frequency band that ranges from 30 to 200 Hz. Gamma waves can affect brain functions including control motor skills, perception, attention, memory, and synaptic plasticity (Amo, de Santiago, Barea, López-Dorado & Boquete, 2017).

Alpha waves are typically more prominent in the posterior and occipital regions of the brain, with a typical peak-to-peak amplitude of about 50 µV. Based on the observations, alpha activity is also known to be significant in the posterior and central regions of the brain compared to other areas. Alpha wave activity is induced in a relaxed state when the eyes are closed, and it diminishes when the eyes are open and mental activity is increased. Many individuals experience a notable shift from beta to alpha waves when they close their eyes, indicating sensitivity to the physical state of eyes closed.

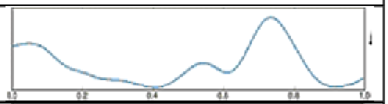
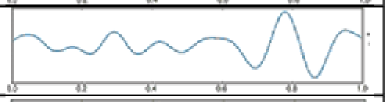
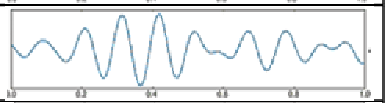
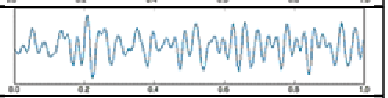
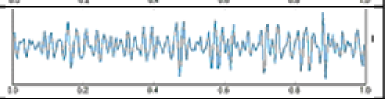
Waves	Frequency bands (Hz)	Behaviour Trait	Signal Waveform
Delta	0.3 – 4	Deep sleep	
Theta	4 – 8	Deep Meditation	
Alpha	8 – 13	Eyes closed, awake	
Beta	13 – 30	Eyes opened, thinking	
Gamma	30 and above	Unifying consciousness	

Figure 2. The brain frequencies ranges and shape generated from the brain (Oon, Saidatul & Ibrahim, 2018).

1.6 Terms and Definitions

Brain plasticity: Brain plasticity, often referred to as neuroplasticity or neural plasticity, is the ability of the nervous system to modify its activity in response to internal or external stimuli by reconfiguring its structure, and connections as well as it's functioning (Mateos-Aparicio & Rodríguez-Moreno, 2019).

Attention Span: Attention span is the ability of an individual to focus on a stimulus or item for a specific duration. This cognitive function is alternatively referred to as sustained attention or alertness (Levin, Bernier, Goldstein & Naglieri, 2011).

Stroop Color and Word Test (SCWT): The Stroop test is a widely used neuropsychological test that evaluates the capacity to suppress cognitive interference. (Scarpina, & Tagini, 2017).

Physically active (PA): The physical movement occurs through the skeletal muscles as a result of the expenditure of energy (Piggin, 2020).

Physical exercise: Any activity that seeks to enhance or sustain one or several aspects of physical fitness. Physical exercise encompasses both aerobic and anaerobic activities, which are distinguished by their particular frequency, duration, and intensity (Mandolesi et al., 2018).

Acute physical activity: Acute physical activity is defined as a single instance or bout of physical activity carried out within a brief period. It is a transitory and temporary type of physical activity usually done during a relatively short timeframe, ranging from a few minutes to a few hours (Basso & Suzuki, 2017).

Executive functions (EFs): Cognition skills include a collection of mental faculties, such as working memory, cognitive flexibility, and self-regulation. Executive functions involve several behavioral and cognitive components and are recognized as having a substantial impact on learning and academic performance (Diamond,2013 ; Baggetta1 & Alexander,2016).

Stroop effect: The Stroop effect refers to the phenomenon where individuals require more time to correctly identify the color of a displayed word when the color and the meaning of the word are incongruent, compared to when they are congruent (Allen, Ruthruff & Lien, 2007).

Independent Component Analysis (ICA): ICA is an unsupervised machine learning methodology that treats a multivariate dataset as a linear mixture of statistically independent hidden elements or components. ICA is a useful tool for separating independent sources linearly mixed in the recorded EEG signals, including artifacts. One of the primary uses of ICA is to perform artifact subtraction in EEG signals (McConn, Lamoureux, Poudel, Palsson, & Sastry,2021; Barborica et al., 2021).

A Finite Impulse Response (FIR) filter: FIR filters, which rely on linear operators, are extensively employed in the field of biomedical signal processing. Their notable feature is their phase linearity, which ensures that the output signal does not exhibit any abnormal time displacements for each of its components (Rivas-Lalaleo et al., 2020). FIR is an impulse reaction filter that performs in one direction with a finite duration. It is used for the quick detection of the EEG signal to smooth and reduce it. Before the data extraction features, which are easily distorted, the artifacts and noise are removed from the data using the FIR (Mahabub, 2019; Bayrak, Demirel & Şamlı, 2020).

Artifact subspace reconstruction (ASR): is a technique that may automatically and effectively remove transitory or high-amplitude artifacts that may be present in EEG data. ASR is meant to have the ability to function online and functions by employing a methodology that involves the use of components. However, there has been a lack of comprehensive attention given to the methodical assessment and documentation of the effectiveness of ASR and the ideal determination of its parameters, especially when it comes to actual EEG data (Chang, Hsu, Pion-Tonachini, & Jung, 2019).

Chapter 2

Literature Review

"What information consumes is the attention of its recipients. Hence a wealth of information creates a poverty of attention."

- Herbert Simon Nobel winner, Economics (1978)

2.1 EEG Technology

EEG sensor is an electronic device that quantifies brain electrical impulses by detecting the diverse electrical signals generated by the activity of a multitude of neurons close to the brain's surface. The EEG device will measure, amplify, and filter the alteration in the electrical signal between the skin and the electrodes (Soufineyestani, Dowling &Khan, 2020).

2.2 EEG Headsets

EEG headsets are available in two variants: wired or wireless. The wired EEG headset will transmit the data to a computer via a physical cable, whereas the wireless headset will transmit the data to the computer either wirelessly or via a Bluetooth connection. A connected EEG connection offers more stability and higher data transfer capacity within a particular time frame, but it lacks the mobility provided by wireless connections.

A primary drawback of wireless EEG headsets is their susceptibility to connectivity issues, which can fail to capture and record brain signal data. However, regardless of the kind of connection, the motion of the cables and electrodes might generate artifacts in the EEG readings by disrupting the connections between the scalp and electrodes (Soufineyestani, Dowling &Khan, 2020).

2.3 Types of EEG Device

The EEG device can be classified into two categories: the dry and wet EEG devices.

2.3.1 Wet EEG devices. There are two categories of wet EEG devices: saline solution EEG and gel-based EEG. Wet EEG systems utilize conductive gel or paste to connect the scalp and the electrode, minimizing electrode impedance. This process necessitates both time and expertise. Additionally, gel traces on the subject's skull must be removed, typically with water (Kam et al., 2019).

2.3.1.1 Soft gel-based EEG device. Through this connection, electrodes establish contact with the scalp by introducing conductive gel into the cavity of each electrode. Following the completion of an experiment, it is imperative to cleanse the headset by eliminating the gel and sanitizing the electrodes. Alcohol is commonly used for this purpose due to its ability to evaporate. (Soufineyestani, Dowling &Khan, 2020).

Figure 3. Soft gel-based EEG device (Emotive).

2.3.1.2 Saline solution EEG device. In addition to the headsets, which necessitate the use of conducting gel to minimize impedance between the sensor and the skin, a saline solution is applied to all the electrodes in the headsets. (Soufineyestani, Dowling &Khan, 2020).

Figure 4. Saline solution EEG device (Crawford, Andujar, Remy& Gilbert, 2014).

2.3.2 Dry EEG device. To obtain high-quality data when utilizing a wet EEG device, it is necessary to cleanse the electrode sites on the scalp and subsequently apply conductive gel to establish an electrical connection with the metal of the electrode. The scalp discomfort that can occur from extended or repetitive data collecting may impose limitations on this connection. An electrode system that eliminates the need for site preparation or conductive gel offers several advantages: it saves time in experiment setup, minimizes errors resulting from gel drying or improper electrode application, and enables longer studies and multiple data collections. Furthermore, this technology not only offers benefits to the researcher but also significantly enhances the comfort and convenience for participants, hence broadening the range of potential applications.

Over the years, "dry" electrodes have been extensively researched and proven to be highly effective in capturing electrocardiographic (ECG) and electromyographic (EMG) signals, offering numerous advantages. However, it is worth noting that both ECG and EMG signals are significantly more powerful than EEG signals. Consequently, developing a system that can detect EEG signals while also being resistant to noise and maintaining reliability over time has proven to be a challenging task (Zender et al., 2011).

Figure 5. Dry EEG headset (https://www.bitbrain.com/neurotechnology-products/dry-eeg)

2.4 Electrode Placement Standards

EEG is a diagnostic technique used for a broad range of conditions including epilepsy, sleep disorders, encephalopathies, and coma, among others (Rojas et al., 2018). The American Clinical Neurophysiology Society proposed two standardized methods for placing electrodes on the scalp: the 10–20 system and the 10–10 system. These values indicate the specific distances between neighboring electrodes positioned on the skull (Soufineyestani, Dowling & Khan, 2020).

The international 10-20 system was created to establish a uniform method for placing EEG electrodes. This technique takes into account four specific anatomical landmarks, namely the nasion, inion, left tragus, and right tragus, as well as the measurement of head circumference. The distances between the anatomical landmarks in this method are quantified and the points are delineated based on proportions equivalent to 10% and 20% of these distances (Silva, L., Silva, K., Lira-Bandeira, Costa-Ribeiro, & Araújo-Neto, 2021).

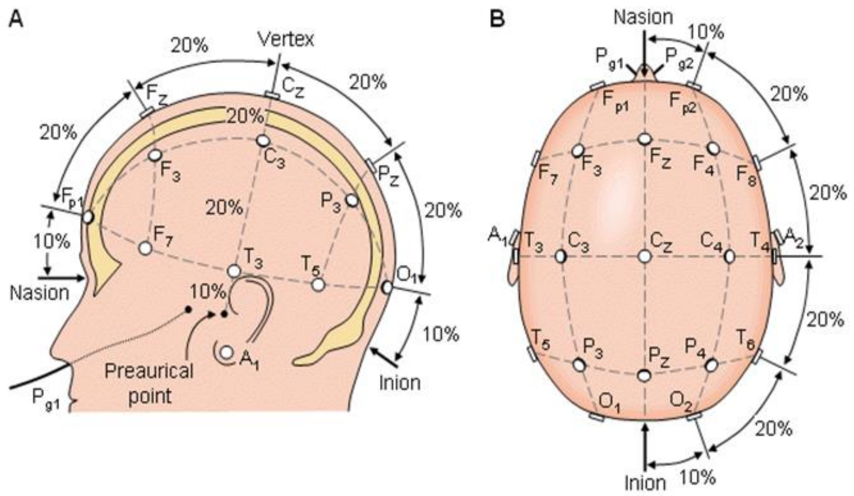


Figure 6. EEG 10-20 Electrode Placement (Shriram, Sundhararajan & Daimiwal,2013).

The location of electrodes is determined by the size and shape of the skull, covering all regions of the brain: F = Frontal, T = Temporal, P = Parietal, and O = Occipital. The numbering scheme designates Odd for the left side, even for the right side, and Z for the midline (Morley, Hill & Kaditis, 2016).

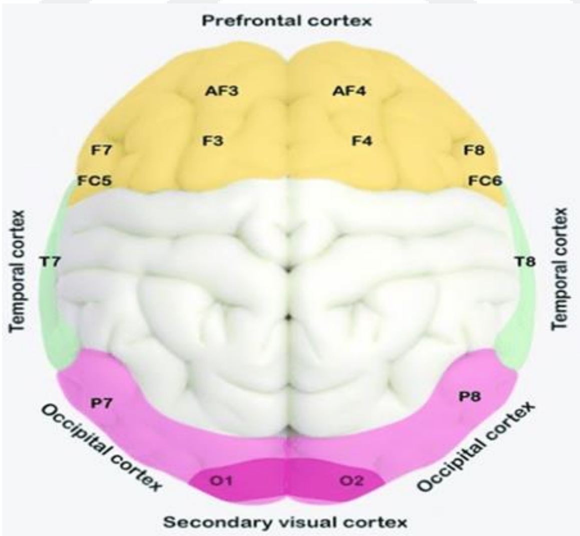


Figure 7. Electrode placement related to each cortex of the brain (Vieira et al., 2020).

2.5 Characteristics of EEG

Waveforms can be characterized according to their location, magnitude, frequency, shape, consistency (regular, sporadic, or constant), synchronization, balance, and reactivity. The waveforms that are most frequently examined are represented in Table 1 (Nayak & Anilkumar, 2023).

Table 1

Brain Wave with their Frequency, Interpretation, and Location.

Band Name	Frequency (Hz)	Interpretation	Location
Gamma	>30 Hz	Problem-solving and concentration	Very localized
Beta	13-30 Hz	Active thinking	Frontal and central regions
Alpha	8-13 Hz	Relaxed state of consciousness	Occipital and parietal
Theta	4-8 Hz	Relaxed state of meditation	Temporal, parietal, and frontal
Delta	0.5-4 Hz	Deep sleep	Central cerebrum and parietal lobes

2.6 Artifacts in EEG Signal

Artifacts are signal sequences that exhibit increased amplitude and different forms compared to brain-generated signal sequences. In other words, artifacts refer to any signal that is not produced by the brain. These artifacts will interfere with the recorded EEG signals, resulting in an erroneous outcome. The artifacts might arise either from the patient or from external factors such as the environment or the equipment (Teplan,2002).

2.6.1 External/Non-physiological artifacts. This artifact is a result of either the environmental conditions or the device itself. There are multiple variations of it.

2.6.1.1 Transmission-line artifacts. The transmission-line or power-line interface operates at a frequency of 50 Hz, facilitating its integration with the beta band as the EEG signal falls within a frequency range of 0.5 to 60 Hz. To eliminate these kinds of artifacts, a notch filter with a frequency range of 50 Hz can be employed (Tandle & jog, 2015).

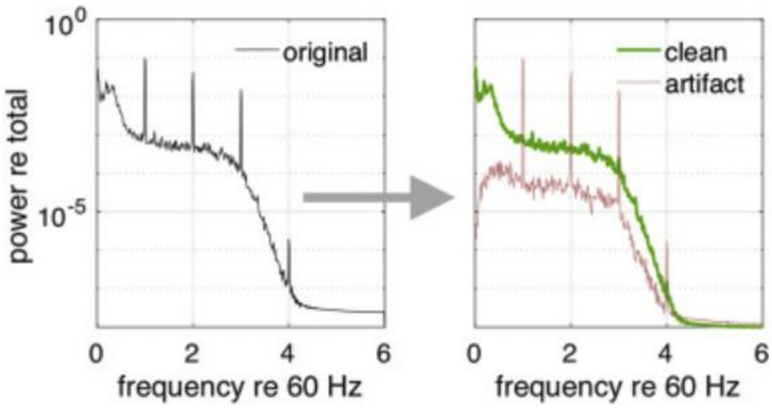


Figure 8. Transmission-line artifacts (de Cheveigné, 2020).

2.6.1.2 Phone artifacts. High-frequency signals are present in the EEG signal due to the phone, thus, to avoid this form of interference, refrain from using the phone throughout the experiment recording (Tandle & jog, 2015).

2.6.1.3 Electrode connection artifacts. This artifact arises due to the inadequate connection of the electrodes, resulting in an amplification of frequency artifacts. (Tandle & jog, 2015).

2.6.1.4 Electrode pop artifacts. Presents as distinct and well-defined interruptions in the background activity, sometimes mistaken for a tumor (Tandle & jog, 2015).

2.6.1.5 Lead movement artifacts. Lead movement has a more disorganized shape that doesn't look like real EEG activity in any way. It commonly contains double phase reversal, which signifies phase reversals without the evenness in polarity that demonstrates an electrical signal coming from the brain (Tandle & jog, 2015).

2.6.1.6 Perspiration artifacts. This artifact is characterized by the presence of low amplitude, swelling waves that last for more than 2 seconds (Tandle & jog, 2015).

2.6.1.7 Physical movement artifacts. This artifact arises from the disruption of electrode contact due to physical motion. (Tandle & jog, 2015).

2.6.2 Internal/ Physiological artifacts. This type of artifact includes artifacts created by humans themselves. There are four specific categories of artifacts within this category, which are outlined below.

2.6.2.1 ***Ocular artifact.*** The presence of ocular artifacts, also known as eye artifacts, produces a notable disturbance in the recorded EEG signals. This artifact is a result of ocular movement, eyelid movement, or blinking. Blinking artifacts exhibit greater amplitude in the recorded EEG signal, whereas the specific direction of eye movement (horizontal or vertical) and eyelid movement result in distinct alterations in the EEG signal. EOG artifacts can be detected in the EEG signal as a representation of this particular sort of artifact (Jiang, Bian &Tia, 2019; Kaya, 2019).

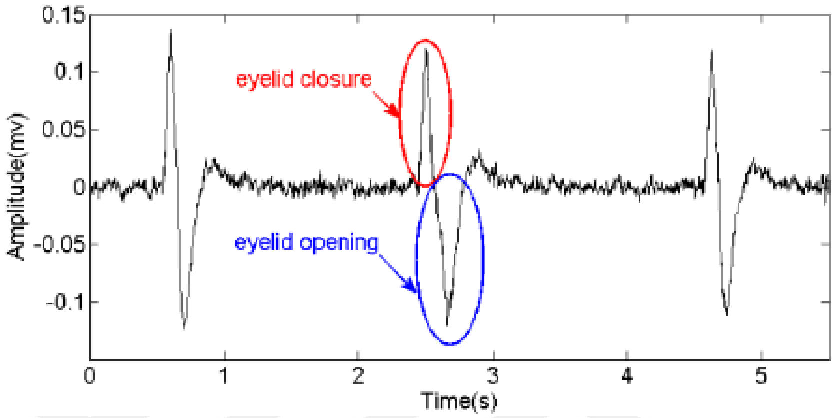


Figure 9. The blinking artifact in the EEG signals (Abo-Zahhad, Ahmed, & Abbas, 2015).

2.6.2.2 Muscular artifact. These artifacts are created by the muscle potentials present on the scalp. The head, face, and neck muscles possess autonomous myogenic actions that extend throughout the entire scalp. The muscular manifestations differ based on the specific muscle type and the level of tension. The EEG signal might exhibit an EMG artifact, which corresponds to this sort of artifact (Kaya, 2019).

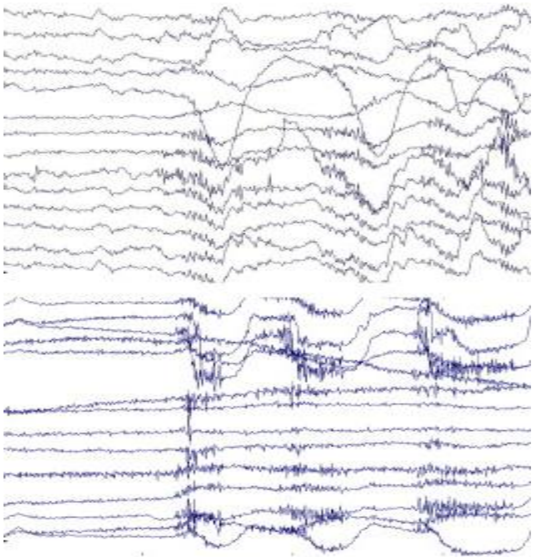


Figure 10. Head movement artifact in the EEG signal (O'Regan& Marnane, 2013).

2.6.2.3 Cardiac artifacts. This artifact occurs when the electrodes are positioned on or close to a blood vessel. Due to this placement, the pulsation and dilation of the blood vessel will generate an artifact in the EEG data. This artifact can manifest in the EEG signal as an ECG artifact (Jiang, Bian & Tia, 2019; Kaya, 2019).

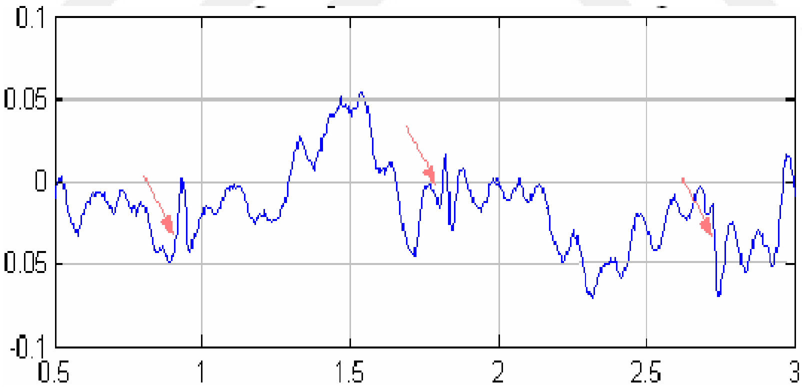


Figure 11. Cardiac artifact in the EEG signal
(Correa, Laciar, Patiño & Valentinuzzi, 2007).

2.6.2.4 Other artifacts. These artifacts are a result of the movement of the head, body, and limbs, which leads to irregular high-voltage disturbances in the EEG data (Kaya, 2019).

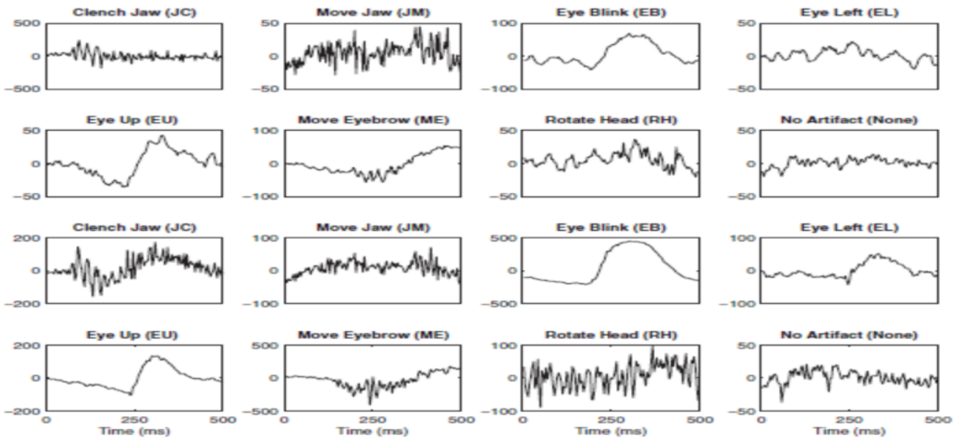


Figure 12. Other artifacts examples (Lawhern et al., 2012).

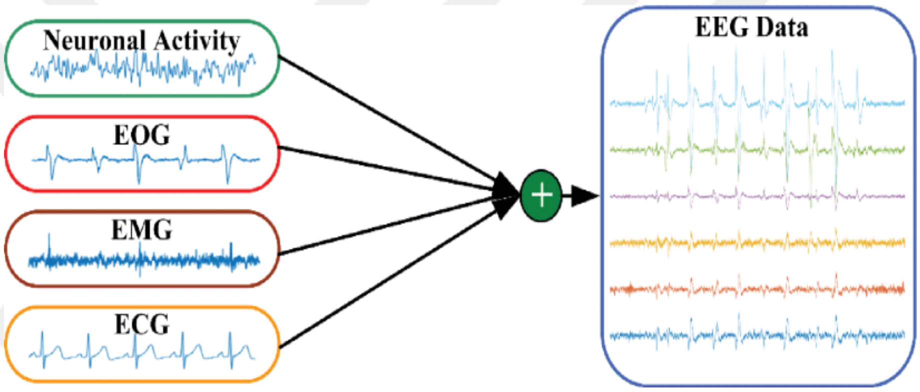


Figure 13. Different physiological artifacts present in EEG signal (Mannan, Kamran & jeong ,2018).

2.7 Theories of Attention

Attention is a multifaceted process that plays a role in achieving and sustaining a state of alertness, directing focus toward certain sensory stimuli, and controlling thoughts and responses deliberately and purposefully. Attention is contingent upon three distinct yet interconnected networks: the "orienting," "alerting," and "executive" networks (Commodari, 2017).

2.7.1. Brain elasticity. Brain elasticity, often referred to as neuroplasticity or neural plasticity, is the capacity of the nervous system to modify and adjust its activity in response to external stimuli by restructuring the structure, functions, or connections of the nervous system. Neurons possess a crucial characteristic in which the nervous system may alter the intensity and effectiveness of synaptic transmission through various activity-dependent mechanisms, commonly known as synaptic plasticity. (Mateos-Aparicio and Rodríguez-Moreno, 2019).

The concept of attention can be classified into various sorts based on whether it is focused on external or internal information. Therefore, there are two types of attention: perceptual attention, which directs external attention to the selection and regulation of sensory information, and central/reflective attention, which is internal attention that involves cognitive control and the contents of working memory, long-term memory, task set, or response selection. The cognitive control system determines which perceptual information to prioritize, encode, and preserve in working memory, while simultaneously suppressing irrelevant sensory input, regardless of the sensory modality (Drigas & Karyotaki, 2019).

The attention types can be categorized into four distinct types: Sustained attention, Selective attention, Divided attention, and Alternating attention (Chung-Fat-Yim, Calvo & Grundy, 2022).

Sustained attention refers to the ability to maintain a response and continuous effort over a period of time. Selective attention, on the other hand, involves the process of selecting and focusing on specific input for further processing while disregarding irrelevant or distracting information. The third category is known as Divided attention. Divided attention is the cognitive ability to simultaneously comprehend multiple pieces of information within a certain time frame. The diminished split attention is a result of the restricted cognitive function following a Traumatic Brain Injury (TBI). When the system becomes overloaded, crucial information may be lost (Cristofori & Levin, 2015). Alternating attention refers to the capacity to transition between tasks by temporarily pausing one task to engage in another one, and subsequently resuming the original task (Commodari, 2017). Figure 14 illustrates the many forms of attention, accompanied by a brief description for each category.

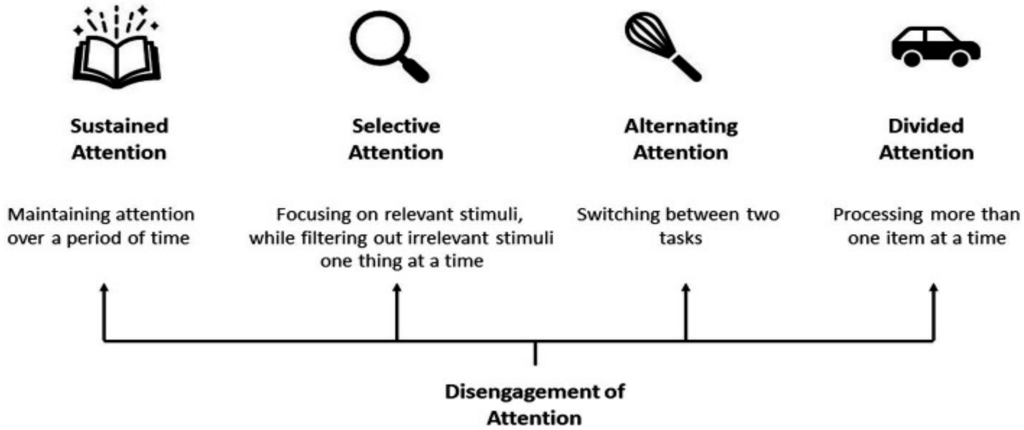


Figure 14. Types of attention with their short description (Chung-Fat-Yim, Calvo & Grundy ,2022).

2.7.2. Attention span. A decreasing attention span is a significant issue in the era of computers and digital media. Currently, the products will be advertised to all age groups, whether they are electronic or digital, to convey the promotional message. Marketing organizations are encountering a challenge due to the excessive promotional activity on electronic and mobile platforms, which has resulted in a change in the timing of customer response to garner attention (Subramanian, 2017).

In recent years, numerous studies have been conducted on the decline of attention. Reported that the mean duration of focus is diminishing, declining from 12 seconds in the year 2000 to eight seconds in 2013. That is shorter than the nine-second attention span of an ordinary goldfish (Subramanian, 2018).

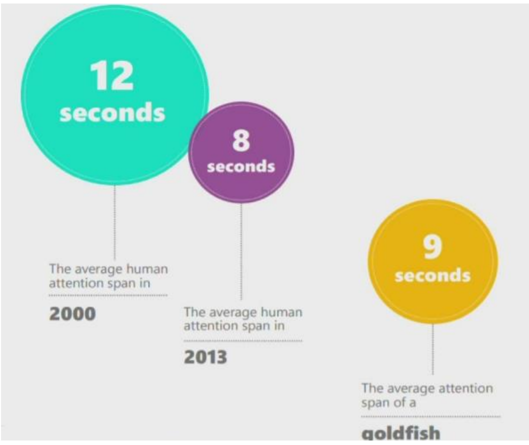


Figure 15. Human attention spans through the years (Subramanian,2018).

2.8 Physical Activity Benefits

Engaging in physical activity guarantees and provides significant health advantages. Almost everyone can derive significant advantages from being physically active. The research indicates that engaging in regular physical activity can lead to a minimum risk reduction of 20%-30% for over twenty-five chronic medical disorders and premature mortality. The International Physical Activity Guidelines (Warburton & Bredin, 2016) strongly advocate engaging in 150 minutes of physical exercise per week at a moderate to strenuous level.

The health benefits of physical activity (PA) are well-documented and include improvements in body composition, prevention of overweight and obesity, as well as enhancements in skeletal, metabolic, and cardiovascular health. Engaging in physical activities not only enhances one's bodily well-being but also yields psychosocial advantages. These include reducing symptoms of sadness, tension, and anxiety, while simultaneously bolstering self-confidence and self-esteem. Regular physical activity is crucial for individuals of all ages, but it is particularly essential during the formative years for promoting healthy growth and development, enhancing cardiometabolic function, and preventing chronic disease (Hills, Dengel & Lubans, 2015).

Figure 16 shows the advantages of exercise on various aspects of the body, including the brain, nervous system, heart, muscles, and immune system. Exercise improves insulin sensitivity, muscle mass and contractility, and mitochondrial content and quality. It also enhances the immune system and promotes the production of antioxidants. Additionally, exercise has a positive impact on hormonal adaptation, inflammation, and fatty acid oxidation. All these benefits contribute to improving an individual's overall health span.

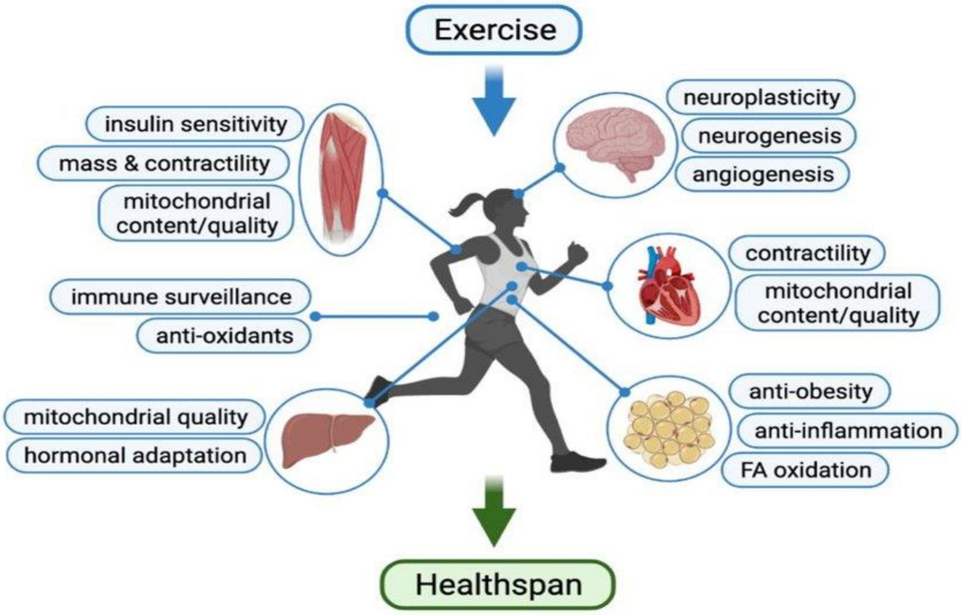


Figure 16. Health benefits of physical activity (Guan & Yan, 2022).

Exercise can improve the functional adaptability of the heart, leading to an increase in cardiac output and a decrease in the risk of arrhythmia (Nystoriak & Bhatnagar, 2018). The heart is not only a vital organ, but it is also a muscle, and individuals who engage in regular exercise can strengthen it. Consequently, physically active, and athletic individuals have a lower resting heart rate variation (HRV) due to their heart being in good condition. This makes it easier for the heart to carry out its function and reduces the risk of coronary heart disease. In contrast, individuals who are physically inactive and lead sedentary lifestyles tend to have poor physical fitness. Consequently, their hearts also become less fit, leading to increased workload and the need for more beats to meet the body's oxygen demands. This results in a higher resting heart rate variability and an elevated risk of developing coronary heart disease (Sinha et al., 2023).

2.9 Stroop Test

The Stroop test is a commonly employed test to evaluate executive function that measures selective attention, processing speed, response inhibition, and cognitive flexibility. The Stroop test was initially developed by John Ridley Stroop in 1935 (Savas, Yerlikaya, Yener, & Taner, 2020).

The Stroop Color and Word Test (SCWT) is a widely used neuropsychological test that evaluates the capacity to suppress cognitive interference. This interference arises when the processing of one stimulus characteristic hinders the simultaneous processing of another stimulus attribute, commonly referred to as the Stroop Effect. The objective of this study is to assess the theoretical validity of several scoring techniques employed to quantify the Stroop effect (Scarpina & Tagini, 2017).

The Stroop effect is observed when a word that symbolizes a color in its meaning (e.g., the word red) is displayed on a monitor screen in a different color (e.g., blue ink color) or the same color (in this case, red), and a participant is instructed to identify either the word or the color. Generally, the response time is longer in situations where there is a conflict, such as when the word "red" is shaded blue (referred to as "incongruent"), compared to situations where there is no conflict, such as when the word "red" is shaded red (referred to as "congruent"). The Stroop effect refers to the cognitive interference that arises when there is a conflict between mismatched stimuli (Taghipour, Bartha, Schlittmeier & Schäffer, 2020).

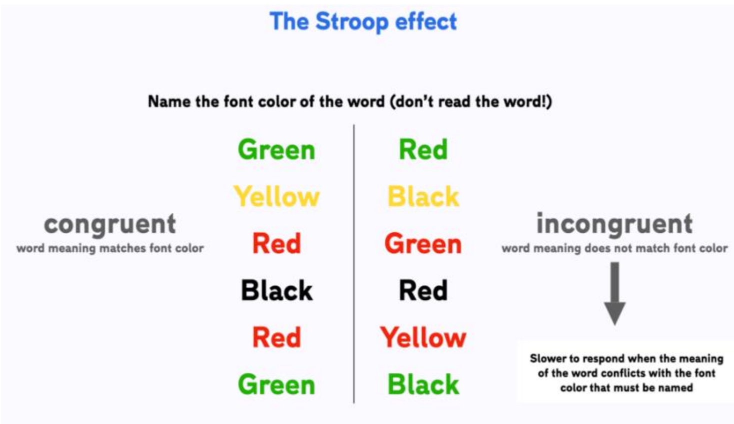


Figure 17. Stroop test (Testable).

The Stroop effect value can be quantified by comparing the speed taken to answer incongruent and congruent stimuli. The Stroop effect is calculated by subtracting the speed taken to answer congruent stimuli from the speed taken to answer incongruent stimuli.

There are studies in the literature that reveal that the Stroop test is accepted as a valid tool to assess the cognitive levels of participants during tasks and being experienced on the test has no significant influence on the test performance. For example, in 2012, research aimed to determine the effect of caffeine on cognitive function using the Stroop test and to investigate whether practicing the Stroop and then repeating it influences the performance in the test results or not. The results of this study suggested that practicing the test and being experienced did not affect the performance in the Stroop task. The results showed that Stroop interference was reduced, and the facilitation was increased after caffeine intake (Dixit, Goyal, Thawani & Vaney, 2012). Another research article evaluating the Stroop test as a tool to indicate the level of cognitive function activation before coffee and after coffee ingestion was published in 2020 (Yuan, Li, Ren & Chen, 2020). The findings of the behavioural experiments involving 31 healthy subjects and Stroop task results suggest that coffee can modulate task performance efficiently and effectively through the provision of feedback information regarding response time and accuracy rate.

2.10 Power Spectrum

The power spectrum or power spectral density, represents the signal's "frequency content," or how signal power is distributed concerning frequency. Several parameters obtained from the power spectrum such as the median and spectral edge frequencies, total power, and spectral band power have been used, (Dressler, Schneider, Stockmanns & Kochs, 2004).

By using power spectral density (PSD), it is possible to quantify the physiological activity of parallel-arranged and space-averaged cortical cells. The computation of EEG PSD is frequently performed using a parametric autoregressive model, which provides information regarding the signal power within each comparatively narrow frequency sub-band (Wang et al., 2015).

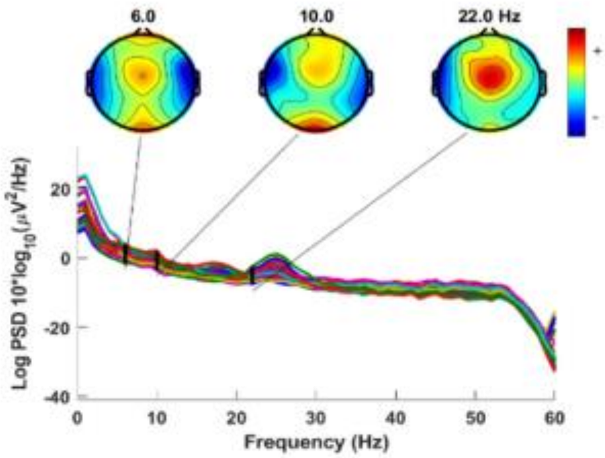


Figure 18. Power spectrum density (Aljalal, Aldosari, AlSharabi, Abdurraqeeb, & Alturki, 2022).

2.11 Scalp Map Visualization (Voltage Map)

Scalp map topography, also referred to as voltage map, is an EEG analysis visualization method that uses the cursor on the EEG recording to depict the distribution of negative and positive potentials on the scalp at a specific point in time. These maps represent the electrical activity that covers the surface of the skull and might be presented in two or three dimensions. Researchers and clinicians can facilitate the interpretation of brain activity patterns by determining the orientation and location of the cortical source producing EEG signals through the analysis of voltage maps (Beniczky& Schomer, 2020).

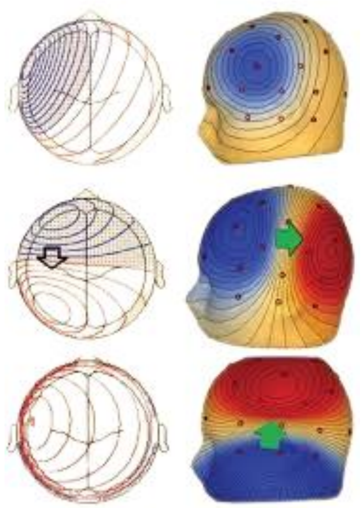


Figure 19. Scalp voltage map in two and three dimensions with different orientations (Foged, Scherg, Fabricius & Beniczky, 2022).

2.12 Previous Studies

Executive functions are crucial for decision-making, self-control, and the acquisition of perspectives through ongoing cognitive flexibility and the modulation of automatic thinking (Garrett, 2022). Over the last ten years, scientists and researchers have focused on examining the impact of physical exercise on brain activity, particularly cognitive function. Scientists and researchers have diligently worked to uncover the factors contributing to poor memory and cognitive impairment in those who are physically inactive. Their goal is to find a reliable solution to enhance these abilities.

Physical exercise (PE) is a powerful gene modulator that produces both structural and functional changes in the brain, leading to significant benefits for cognitive performance and overall well-being. Physical exercise is also an inhibitor of neurodegeneration. Nevertheless, it remains uncertain whether this protection is achieved by altering the molecular pathways that cause neurodegeneration or by enhancing the ability to defend against harmful assaults (Mandolesi et al., 2018).

In 2014, a research article conducted a counterbalanced crossover randomized trial to examine the impact of acute high-intensity aerobic exercise on cognitive function. The study involved 42 female participants who were nonsmokers and did not have any depression, cerebral, cardiovascular, respiratory, color vision dysfunction, or neuromuscular disorder. None of the participants were taking any medication. The participants in this study were involved in a physical fitness program for a period of three to nine months. Before the study began, the participants were required to undergo a cognitive test, either the Stroop test or the tail-making test (TMT), as well as a familiarization session for the exercise protocols. After a week from this session, the participants will randomly perform cognitive function tests between 2 p.m. and 6 p.m. The interventions consisted of aerobic activity, strength exercise, and a control group. In this study, researchers discovered that engaging in both acute aerobic and strength training enhances executive processes. However, this beneficial impact appears to rely on the specific task and executive function (Alves et al., 2014).

In 2015, a research study was published to examine the impact of a single session of physical exercise and four weeks of exercise training on an individual's resting state electroencephalographic alpha peak frequency (APF). The APF is a neurophysiological marker that indicates an individual's level of arousal and attention.

The study involved 10 male volunteers with an average age of 22.7 ± 2.0 years, weight of 70.6 ± 6.9 kg, and height of 180 ± 4.8 cm. During the experiment, the participants completed both a steady-state exercise protocol and an exhaustive exercise protocol on separate days. EEG recordings were taken 2 minutes before exercise, immediately after exercise, and 10 minutes after exercise. The study found that the APF significantly increased after the exhaustive exercise protocol but did not increase after the steady-state exercise protocol. Gutmann et al. (2015) found that strenuous exercise leads to an increase in APF, suggesting a heightened state of arousal and readiness for external stimuli (Gutmann, et al., 2015).

In 2016, a research study was conducted to examine the impact of high-intensity sprint-based running exercise lasting approximately ten minutes on the cognitive function of teenagers. The study involved 47 participants aged 12.6 ± 0.6. Three participants did not complete the experiment, leaving a total of 44 participants (21 males and 23 females). Before the first trial, the researchers measured the participants' height, body mass, and waist circumference during a familiarization session. The participants were instructed to have a meal of their choice in the evening before the first trial and to repeat this meal for subsequent trials. Following the meal, the participants were required to fast from 10 p.m., except for drinking water as desired, and to avoid any strenuous exercise for 24 hours before the trial. The exercise sessions took place in a school sports hall with a group of participants ranging from eight to twelve individuals at a time. The participants began with a warm-up, followed by stretching of the lower limbs. They then engaged in high-intensity intermediate running, consisting of ten-second sprints followed by fifty seconds of walking. This cycle was repeated ten times, resulting in a total exercise duration of ten minutes. Throughout the experiment, the researchers measured the participants' heart rate at various points, both during rest and exercise. Additionally, the researchers utilized the Stroop test to assess sensitivity to interference and the ability to inhibit automated responses. They also employed the digit symbol test and the Corsi blocks test. The study found that sprint-based exercise improved cognitive function speed but had no impact on visuospatial working memory or general psychomotor speed (Cooper et al., 2016).

In 2018, a systematic review was published to examine the impact of physical activity on several aspects of executive function, attention, and academic achievement in preadolescent children aged six to twelve years. The researchers employed a methodical quantification to assess the impact of physical activity on these areas. The researchers conducted a comprehensive search of databases and reviewed relevant studies from 2000 to 2017. They identified only thirty-one intervention studies that met the inclusion criteria. The researchers categorized these studies into three distinct domains, each with its subdomains. The attention domain consisted of selective attention, divided attention, and sustained attention. The executive functions domain included inhibition, working memory, cognitive flexibility, and planning. The academic performance domain encompassed mathematics, spelling, and reading. The systematic review and meta-analysis concluded that acute physical activity has a beneficial impact on attention. Additionally, the longitudinal physical exercise program demonstrated positive effects on the three domains of performance in preadolescent children. Therefore, physical activities have a positive effect on all three domains of performance in this age group (De Greeff, Bosker, Oosterlaan, Visscher, & Hartman, 2018).

In 2018, a study was released examining the impact of physical activity on resting heart rate (RHR). The researchers aimed to evaluate if regular exercise or participation in sports has an influence on RHR in healthy individuals. Various sorts of sports were utilized in the investigation. This research study utilized six databases to identify controlled trials investigating the impact of physical activity or sports on resting heart rate (RHR) in healthy persons. This research was summarized using meta-analyses. None of the participants exhibited overweight, obesity, arterial hypertension, or dyslipidemia. If the participants in the study were engaging in regular exercise at the start of the trial, this did not result in their exclusion from the study. The findings of this study indicate that the reductions in resting heart rate (RHR) caused by exercise were positively associated with the initial RHR and inversely correlated with the average age of the subjects. Specifically, endurance training and yoga were found to be effective in lowering RHR. This phenomenon may lead to a decrease in overall mortality as a result of consistent physical exercise or participation in sports (Reimers, Knapp & Reimers, 2018).

A study conducted in 2019 at Lehigh University examined the performance of sixteen participants, including both males and females, on a standardized set of concussion assessment tools and EEG measurements. The study aimed to measure how athletes performed before and after engaging in acute exercise, in order to simulate the conditions of athletic competition. The study measured athlete performance using a standardized set of concussion evaluation measures and EEG readings both before and after acute exercise, to simulate the conditions of athletic competition. The researchers employed many assessments, such as the King-Devick test (K-D test) and the Standardized Assessment of Concussion (SAC) component of the Sport Concussion Assessment Tool (SCAT3). Before and after the exercise challenge, data on heart rate and arterial oxygen levels were gathered. The exercise challenge involved running a distance of 1.6 km. The study found that gender significantly influenced these effects, with exercise having the greatest impact on performance among female athletes. EEG activity in the theta frequency range (4–8 Hz) was reduced during periods of calm relaxation, whether with eyes open or closed. In addition, exercise resulted in a decrease in the EEG activity during the K-D test and a change towards higher frequencies during the balance evaluation of the SCAT3 (Devilbiss et al., 2019).

In the same year, another research study was conducted. This study seeks to examine the features of acute physical exercise and cognitive literature to emphasize possible directions for future research and techniques. The study examines the impact of aerobic exercise of moderate to intense intensity, lasting between sixteen to thirty-five minutes. The participants in this study were individuals aged between eighteen and thirty-four years (Pontifex et al., 2019).

A research study conducted in 2020 sought to examine the correlation between objective neuropsychological performances and the continuous monitoring of physical activity. The correlation between cognitive function and daily physical activity can be assessed by utilizing continuous three-axis accelerometers in the Xiaomi Mi Band. The average number of steps, distance, and calorie expenditure per day over a seven-day period will be calculated and documented for each subject. The slope of the receiver operating characteristic curve was utilized to ascertain the metrics of activity to make comparisons between early-stage MCI and late-stage MCI. The study assessed MCI patients by employing two cognitive tests, namely the Cognitive Abilities Screening Instrument and the Chinese Version Verbal Learning Test (Chang, 2020).

In 2020, another research paper was published. This study utilized nineteen participants to examine the dose-response relationships. Specifically, they investigated the impact of exercise duration on both subjective and objective cognitive function, visual memory task performance, and arousal levels. In this study, participants were instructed to perform three distinct interference tasks, each including cycling for either fifteen, thirty, or forty-five minutes at a maximal oxygen volume (VO_2 max) ranging from sixty to seventy percent. Both cognitive and arousal assessments were conducted prior to and following a duration of less than two minutes of the exercise. All three interferences had a substantial impact on self-reported arousal, heart rate (HR), and rating of perceived exertion (RPE), with similar magnitudes of effect. Ultimately, the beneficial impacts of physical activity on both the individual's health and cognitive abilities, such as inhibition and task-switching, could still be enhanced. Aerobic exercise for a duration of fifteen minutes was found to be capable of eliciting favorable alterations in self-perceived arousal. The processing speed of visual recognition memory and attention remained unchanged. The study conducted by Hacker, Banzer, Vogt, and Engero (2020) found that engaging in physical activity for more than fifteen minutes has a detrimental effect on the accuracy of visual recognition memory. (Hacker, Banzer, Vogt & Engero ,2020).

In 2021, a research study was conducted to examine the neurological mechanisms underlying physical exercise habits in both elderly and young individuals. The study involved thirty-six healthy young participants and thirty-five healthy elderly participants. Electrocardiography (ECG), Electromyography (EMG), and Electroencephalography (EEG) were used to collect data. Each participant completed three cycling sessions, each lasting five minutes, with varying exercise intensities. At the conclusion of this study, researchers discovered that there was a significant positive association between the EEG spectral power of physically active older individuals, who engaged in regular exercise, and the intensity of their exercise. This correlation was determined using Pearson correlation analysis. The study found that exercise enhances cortical activity in physically active senior adults, with a significant p-value of less than 0.001. No significant association was seen between spectral power and exercise intensity in older individuals who engaged in occasional exercise. According to Lin et al. (2021), the young individuals who engaged in regular exercise had enhanced efficiency in both their heart and brain functions (Lin et al. ,2021).

In 2021, a research study was conducted to observe the electroencephalogram (EEG) of fifteen people while they were sat on a cycle ergometer. The study aimed to analyze the EEG before, during, and after a cycling activity, while participants had their eyes open and closed. The exercise intensity ranged from light to moderate. The EEG power spectrum densities were computed for alpha frequency band activity within the range of 8 to 13 Hz. During rest, the level of alpha brainwave activity was significantly higher when participants had their eyes-closed compared to when their eyes were open at the occipital site. Additionally, the combined effect of closing the eyes and engaging in acute light-to-moderate intensity exercise resulted in a significantly greater increase in alpha activity than the sum of the effects of each factor individually. This indicates a synergistic effect. The researchers concluded that engaging in acute light-to-moderate intensity exercise with the eyes-closed enhances alpha brainwave activity in a synergistic manner (Komiyama et al., 2021).

In 2022, a research study was conducted to examine the immediate impact of moderate to vigorous physical activity (MVPA) on executive function (EF) in children with ADHD. Additionally, a meta-analysis was performed to analyze the effects of MVPA on task components that involve both lower and higher EFs. The study involved ten participants. The study's conclusion was that meta-analysis indicates a slight positive impact of engaging in a single bout of moderate-to-vigorous physical activity (MVPA) on the performance of tasks that require both lower and higher executive functions (EFs) in children with ADHD. This suggests that a single bout of MVPA could be used as a nonpharmaceutical adjunctive treatment option with minimal adverse effects, as it temporarily enhances EFs (Chueh et al., 2022).

In 2023, a study conducted a systematic review and meta-analysis to estimate the impact of physical activity (PA) on inhibitory function in children with ADHD. The researchers identified a total of 2198 articles by searching various databases including PubMed, The Cochrane Library, Web of Science, EBSCO (MEDLINE, APA Psyclnfo, ERIC), Embase, Scopus, and ProQuest. Additionally, one article was manually identified. Endnote X9 imported all of these articles, resulting in a total of 1278 after deduplication. Initially, sixty-two publications were screened based on the title and abstract. Eventually, eleven articles were selected for quantitative synthesis. The findings of this systematic review study have validated the prior meta-analyses' findings on the positive impact of physical activity (PA) on both overall cognitive function and inhibitory control in children with ADHD. Further examination revealed that the frequency, intensity, duration, kind, and length of intervention had a significant impact on the effect of physical activity in enhancing inhibitory control in children with ADHD. Physical activity (PA) can significantly enhance the inhibitory function of children diagnosed with attention deficit hyperactivity disorder (ADHD). However, the effectiveness of PA therapies in this regard requires further validation through additional empirical research. The most effective way to improve the interference suppression of ADHD children is to engage in long-term, moderate to vigorous open skill activity, at least twice a week, with each session lasting sixty minutes or more (Wang et al., 2023).

Chapter 3

Methodology

This chapter provides a detailed explanation of the study methodology utilized by the researcher. Following the goals and research questions stated in the introduction section. This study includes the description of the research design, the specific population being studied, the size of the sample, the methods used to gather data, and the analytical tools utilized.

3.1 Study Design

The study design employed for this thesis is a quasi-experimental pre-test and post-test, nonequivalent group method. The study examined the impact of physical activity on cognitive function and attention. The second phase involves the selection of specific data parameters, such as gender (male), health status (healthy), age range (18–30 years old), and smoking status (nonsmokers).

The third phase, known as the experimental stage, comes next. This stage employs the emotive flex and pulse oximeter to collect EEG data and measure heart rate. Additionally, the Stroop test serves as a cognitive assessment to determine the level of attention, and a treadmill serves as a sub-device.

The fourth stage involves analyzing the data gathered during the experimental phase, including measurements of heart rate, the accuracy of answers, the average response time, scalp mapping, and power spectrum analysis.

The EEGLAB software examined the power spectrum and scalp map, while the SPSS software specifically employed t-tests to analyze the remaining data. Lastly, the final phase entails addressing the hypothesis inquiries.

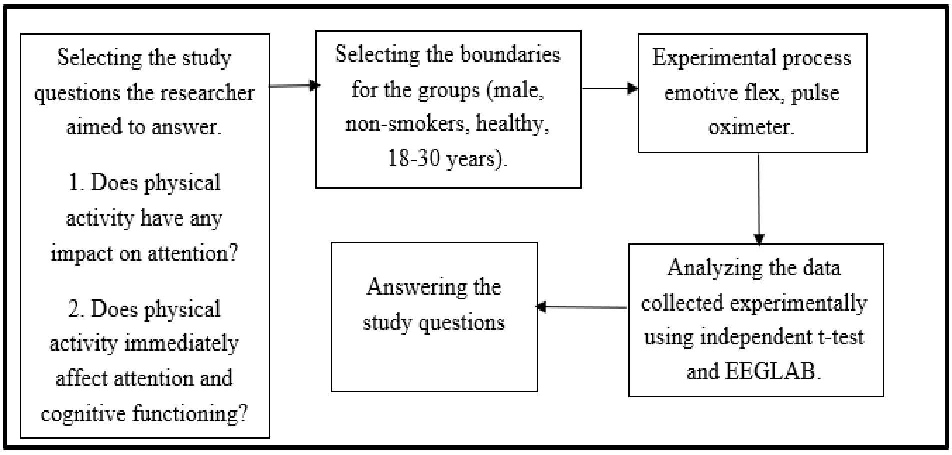


Figure 20. Study design of the thesis

3.2 Participants

The participants were selected through several points.

- Male,
- Age ranging between eighteen and thirty years old,
- Nonsmokers,
- Don't have any medical history of stroke, seizures, or chronic pain and are not overweight. (Tables 2 and 3)

These participants were asked NOT to;

- Drink any type of caffeine including cola, tea, or energy drink for twelve hours before the experiment,
- Take any sedatives and narcotics medicine,
- Drink alcohol at least one day before the experiment,
- Sleep less than seven or more than nine hours,
- Miss any meal before the experiment,
- Neglect drinking enough water during the experiment day.

There were two groups in the study, ten for the physically active and another ten participants for the physically Inactive group, in total twenty participants.

The physically active group was selected from people who go to the gym, doing strength and cardio exercises for at least five months from the experiment with six hours to ten hours per week. The physically inactive group was selected from people who haven't been to the gym before.

During the experiment there is No Audio and/or video recording will be taken in this study. Each participant will be assigned a number, and these numbers will be used when analyzing the data. In case the research is published, your personal information will not be revealed, only group data will be published.

The study was approved by Bahçeşehir University's Ethics Committee and conducted according to the ethical principles of the Helsinki Declaration. Informed consent was obtained from all individuals participating in the study.

Table 2

Characteristics of the Physically Active Group.

No.	Months in gym	Hours per week	Strength activities Days per week	Cardio Minutes per week	Hight (m)	Weight (kg)	Age (Years)
1	36	5-8	4-6	30	1.78	67	23
2	9	6-8	3	40	1.74	62	25
3	5	>6	4	30	1.70	71	30
4	5	6	4	30	1.74	75	27
5	5	5	2	30	1.76	80	21
6	8	6	4	80	1.80	84	30
7	11	8	6	60	1.81	82	19
8	144	9	5	50	1.70	68	29
9	6	6	4	30	1.80	70	21
10	24	6	5	40	1.7	79	22

Table 3

Characteristics of Physically Inactive Group.

No.	Age (Years)	Weight (kg)	Height (m)
1	19	67	1.77
2	21	91	1.99
3	28	78	1.72
4	26	63	1.72
5	19	90	1.84
6	20	79	1.78
7	25	70	1.65
8	22	74	1.70
9	30	70	1.65
10	27	60	1.80

3.3 Procedures

This section contains the data acquisition, experimental protocol, data preprocessing, classification, and statistical analysis stages of the thesis.

3.3.1 Data acquisition. An electroencephalogram is a medical instrument used to quantify the electrical impulses generated by the neurons in the brain. After measuring these signals, the EEG device will proceed to enhance and filter them (Soufineyestani, Dowling & Khan, 2020). The researcher used the emotive flex device to gather the required EEG records. Conducting gel was applied to the electrodes to improve their conductivity. The EEG data were captured from the frontal part of the scalp, specifically targeting the alpha and beta waves in the brain. To capture these waves, the researcher utilized a total of 16 channels: Fz, Fp1, F7, F3, FC1, FC5, FT9, FC6, FC2, FT10, F4, F8, Fp2, O1, Oz, and O2. A total of 8 channels were utilized during eyes-closed trial, specifically P3, P7, Pz, P8, P4, O1, Oz, and O2. The sampling rate was 128 samples per second (SPS). The unprocessed EEG signals underwent digital filtering with cutoff frequencies set at 0.5 Hz and 45 Hz. The signals underwent a visual inspection and any signal segments containing artifacts were eliminated. The electrode placements are determined based on the size and shape of the skull, covering all regions of the brain. The regions are labeled as follows: F for Frontal, T for Temporal, P for Parietal, and O for Occipital. Additionally, the numbering system is used to indicate the location: Odd numbers represent the left side, even numbers represent the right side, and Z represents the midline (Morley, Hill & Kaditis, 2016).

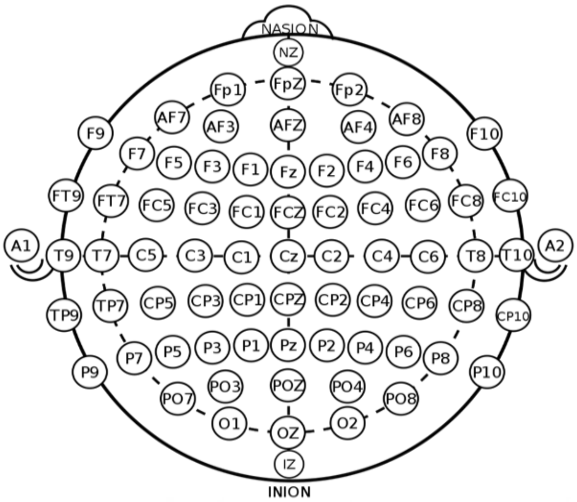


Figure 21. International 10-20 system for EEG electrode placement (Dimitrova, Wagatsuma, Krastev, Vrochidou & Nunez-Gonzalez, 2021).

3.3.2 Experimental protocol. The experiment is conducted in a controlled environment, where the phone is set to airplane mode and the Wi-Fi, lights, and air conditioner are switched off. Exclusive access to the laboratory during the recording will be granted only to the participant and the researcher.

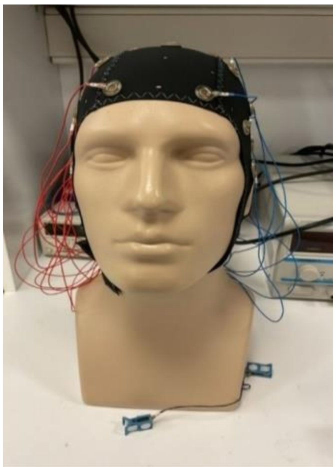


Figure 22. The emotive flex cup with the connecting electrodes.

Before starting the recording, the researcher attached the emotive flex cup, which is already linked to the electrodes, to the participant's head, then connected the controller to the computer. Next, the researcher applied conducting gel to the electrode holes, ensuring that the color of the corresponding circle on the screen changes from black to green. This indicates a strong connection, as opposed to yellow or red, which signify a weak or poor signal. Once all electrodes have been properly prepared with conducting gel and the screen shows a 100% connection, the researcher starts the recording.

Figure 23. The experimental setup used in the study.

Figure 23 represents the subject wearing the emotive flex cup connected with the electrodes and the controller.

The experiment has four recording steps; the participants will close their eyes, and relax, during the recording the participants must not move any part of their body, speak, or have any change in their facial expression. This step lasts for three minutes of recording.

During the second step the participant opened their eyes, focusing on a fixated point in a dim environment, the participant remained calm and steady with no movement in their eyes or blinking, again this step takes another three minutes, after recording the heart rate for the participant during resting state taken using the pulse oximeter.

The third and the last part from the resting state part is the Stroop test part, the participant performs the test using the computer next to the recording screen of the researcher. During this part the participant remain calm and steady, placed their left and right hands on the keyboard placing two fingers from the right hand on the Y and B button, the Y represent the Yellow and represent the blue color, while the left hand placed two fingers on the R and G representing Red and Green respectively. The participant remains steady and during the recording they must not move their eyes to the left and right or blink, they also press the keyboard button gently. This part took approximately one minute and twenty seconds. During the recording the participants answer the test by pressing the keyboard button that represents the color ink of the color words.

After the resting state part, the subject started running for 1.6 km using treadmill in the laboratory, the physically active participants used speed 15, while the physically inactive participants ran with speed ranging 13-15.

After running the researcher measured the Heart rate immediately after finishing the running, the participants returned to their chair and rest for fifteen minutes during the resting period the researcher reconnected the device again, conducting gel applied again into the electrodes holes and the subject repeated the Stroop test part again lasting for one minute and twenty second approximately after fifteen minutes from the running. After the participants finish the test the Stroop effect and the number of correct and wrong answers will appear on the screen, the experiment is finished.

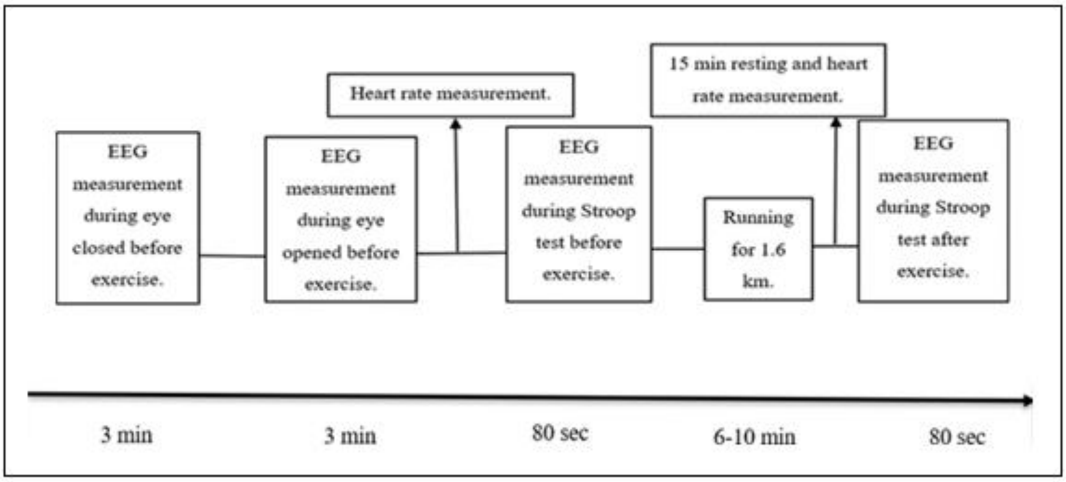


Figure 24. Experimental Protocol used in the study.

The Stroop effect represents the incongruent answers' speed minus congruent answers' in milliseconds.

Lastly, the EDF and CSV signals were taken form from the Emotive program (Tables 4 and 5).

Table 4

The Readings for the Physically Active Group.

Subject	HR before exercise (BPM)	HR after exercise (BPM)	Average response time before exercise (ms)	Average response time after exercise (ms)	Correct answers before exercise (out of 40)	Correct answers after exercise (out of 40)
	Mean = 72.60	Mean = 114.60	Mean = 939.81	Mean = 848.92	Mean = 36.00	Mean = 37.30
	Std = ±11.68	Std = ±18.74	Std = ±106.81	Std=±142.34	Std = ±3.80	Std = ±1.57
1	95	135	931.675	773.73	40	40
2	84	134	912.73	975.33	39	38
3	83	129	1023.08	897.43	39	38
4	75	126	715.85	644.70	38	38
5	68	125	1094.68	875.53	37	38
6	68	110	1023.20	858.25	36	37
7	68	108	838.43	688.30	36	37
8	68	105	964.25	1087.13	35	37
9	59	98	909.23	715.40	33	37
10	58	76	985.00	973.43	27	34

Table 4 shows the mean and standard deviation for heart rate, the average response time, and the correct answers for the physically active group before and after exercise (running for 1.6 km). It has been seen that the mean value of heart rate has increased from 72.60 to 114.60 after the exercise. The time the participant takes to correctly answer the task (the ink of the word written), the shorter it is the quicker and more efficient its cognitive processing. Physically active participants had a 939.81 ms average value for the Average response time before doing, the average time decreased to reach 848.92 ms which means that after exercise the average reaction time decreased which means the participant were faster in answering the task. The average number of correct answers after the exercise increased to 37.30 from 36.00.

In other words, after exercise both the correct answers and the average speed in responding to the stimuli increased after exercise, which means the attention level increased in physically active group after exercise.

Table 5

Readings for the Physically inactive Group.

Subject	HR before exercise (BPM)	HR after exercise (BPM)	Average response time before exercise (ms)	Average response time after exercise (ms)	Correct answers before exercise (out of 40)	Correct answers after exercise (out of 40)
	Mean = 74.00	Mean = 124.30	Mean = 1034.76	Mean = 805.34	Mean = 30.20	Mean =34.60
	Std = ±7.76	Std = ±14.54	Std= ± 276.84	Std = ± 205.42	Std = ±8.16	Std =±6.65
1	87	154	1375.15	831.63	39	40
2	87	134	840.63	592.90	38	40
3	76	130	658.35	745.43	37	39
4	76	129	1441.18	1332.63	36	39
5	75	128	1387.70	861.68	33	36
6	69	125	1040.68	873.95	30	36
7	68	120	989.28	702.63	27	36
8	68	110	804.65	734.68	26	32
9	67	107	994.53	718.95	25	24
10	67	106	815.43	658.93	12	22

Table 5 represents the heart rate, Average response time and the number of correct answers in the physically inactive group. The heart rate increased after exercise, which is expected result, the Average response time decreased to 805.34 ms from 1034.76 ms which means that the participant average speed in answering the task increased after exercise, same increase occurred in the average correct answers after exercise to reach 34.60 from 30.20.

In other words, the attention level increased after exercise since both the average correct answers and Stroop effect increased after exercise.

3.3.3 Data preprocessing. EEG is a Noninvasive process to measure and record the signals of the brain. Since the EEG signals have small amplitudes which make it easier to be contaminated with noise. Most of the artifacts (i.e., the eye blinking, muscle movement) are lying within the EEG waves frequency bands and it may overlap with the brain activities, because of these artifacts the most important step in the data preprocessing is the noise removal. To remove these artifacts from the signal several filters have been used to achieve this goal.

The first filter was CAR (common average reference). CAR filter is commonly used in EEG, where it is necessary to identify small signal sources in very noisy recordings (Ludwig et al., 2009). CAR, a spatial filter could be considered as the subtraction of the common activity of EEG, which left only the idle activity of each EEG in a specific electrode.

x_i^{CAR} (t) = $x_i(t) - \frac{1}{C} \sum_{j=1}^{C} xj(t)$, (Yu, Chum & Sim, 2014).

x_i^{CAR} = filtered output of electrode i^{th}.

$x_i(t)$ = potential between j^{th} electrode and the reference.

C = total number of all electrodes on the scalp.

The second filter was FIR filter with a higher edge of 45 Hz and lower edge of 0.5 Hz. The Finite Impulse Response (FIR) filter is one of the digital filters used for signal processing and filtering applications. FIR filters are characterized by having a finite-duration impulse response, which means that their output response is solely determined by a weighted sum of the input signal's past and present values.

FIR filters are also called as non-recursive filters because the output signal depends only on input signal (Karthick, Senthilselvi, Meenalochini & Senthil Pandi, 2022).

ICA (Independent component analysis) filter is the third filter used during the data preprocessing which filter the EEG data, ICA is a commonly used tool to remove artifacts such as eye movement, muscle activity, and external noise from the data and to analyze activity on the level of EEG effective brain sources. The effectiveness of filtering the data is one key preprocessing step to improve the decomposition that has been investigated previously. However, no study thus far compared the different requirements of mobile and stationary experiments regarding the preprocessing for ICA decomposition (Klug & Gramann,2021).

The fourth and last filter used to filter the EEG data is reject data using clean raw data and ASR. Artifact subspace reconstruction (ASR) is an automatic, online-capable, component-based method that can effectively remove transient or large amplitude artifacts contaminating EEG data. However, the effectiveness of ASR and the optimal choice of its parameter have not been systematically evaluated and reported, especially on actual EEG data. ASR removes more eye and muscle components than brain components. Even though some eye and muscle components are retained after ASR cleaning, the power of their temporal activities is reduced. Study results also showed that ASR cleaning improved the quality of a subsequent ICA decomposition (Chang, Hsu, Pion-Tonachini, & Jung, 2019).

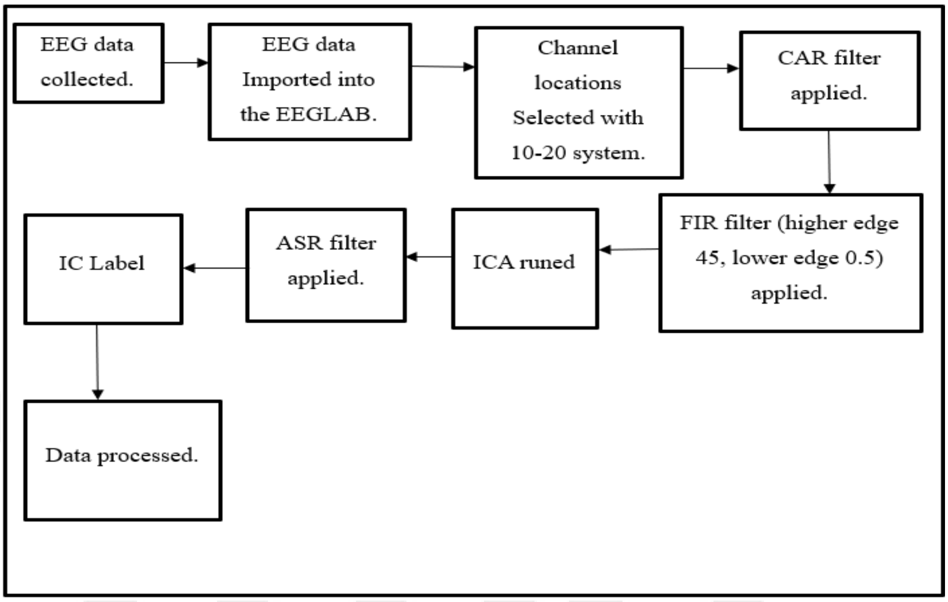


Figure 25. Preprocessing flowchart.

3.3.4 Classification stage. The considerable need for finding new ways to improve attention and cognitive function in individuals, since the attention span for humans has been decreasing these decades. As a result, studying the attention based on the physically active levels on the brain activity, the EEG has been used as a marker to achieve this goal. Therefore, the extracted features are meant to minimize the loss of important information embedded in the signal. This is necessary to minimize the complexity of implementation, to reduce the cost of information processing.

By recording and measuring alpha and beta waves through the experiments. The alpha wave band represents the resting state during the experiment with closed eyes, while the beta wave represents the resting state and active state during the experiment with opened eyes.

3.3.5 Statistical Analysis. The choice of suitable statistical methods in medical research papers is crucial for ensuring the quality of the papers and the trustworthiness of their results. When doing statistical analysis on quantitative data, it is important to consider two crucial factors. There are two tasks: correctly identifying the type of experimental design and verifying if the data fits the preconditions for a parameter test. Alternatively, it can result in various forms of misapplication in some circumstances and potentially yield divergent or contradictory inferences from the same set of data (Liang, Fu & Wang, 2019). There are two types of T-tests. The independent t-test is applicable when the two groups being compared are not related to each other, while the paired t-test is employed when the two groups being compared are related to each other (Kim, 2015). The independent t-test is utilized to determine the statistical significance of the difference between the means of two separate and unrelated samples. Another assumption of the independent t-test is homogeneity of variance, which is verified using the "Levene statistics" (Choudhary, 2018).

3.4 Validation and Reliability

In order to enhance the reliability of the results, the researcher cross-referenced the findings with the previous literature regarding the correlation between physical activity, attentiveness, and frequency band modulation. The validation method was used to verify the coherence of our findings with existing knowledge, hence improving the overall dependability of the study.

3.5 Conclusion

In general, the study into how exercise affects attention and frequency band is suggested to be reliable because it strictly follows stated methods, makes sure that devices are calibrated correctly, and uses strong data processing methods. The findings are suggested to be reliable and used to provide useful insights into the complex relationship between physical activity and neurophysiological responses.

3.6 Limitations

- Dependence on self-reported physical activity levels may induce bias since people may exaggerate or underestimate their actual exercise habits. Accelerometers, which are objective measurements, can help reduce this limitation.
- Attention is a complicated cognitive concept, and the personal nature of attention tests can lead to variability. Using a range of attention evaluation

instruments and taking into consideration various attentional elements might strengthen the reliability of the results.

Chapter 4

Findings

This chapter includes the findings of this research. According to the research questions and aims that were mentioned in the first chapter, this chapter contains the statistical analysis of the data collected throughout the procedure discussed in the third chapter.

4.1 Results

This section includes a summary of the results of the study at which whole data sets will be discussed in the upcoming sections.

Table 6.

The mean, the standard deviation (std), and the level of significance for all parameters.

	Group	N	Mean	Std.	p = 0.05
Heart rate before exercise (BPM)	Active	10	72.60	11.68	0.210
	Inactive	10	74.00	7.76	
Heart rate after exercise (BPM)	Active	10	114.60	18.74	0.311
	Inactive	10	124.30	14.54	
Stroop test Average response time before exercise (ms)	Active	10	939.81	106.81	0.013*
	Inactive	10	1034.76	276.84	
Stroop test Average response time after exercise	Active	10	848.92	142.34	0.693
	Inactive	10	805.34	205.42	
Correct answers before exercise	Active	10	36.00	3.80	0.055

	Inactive	10	30.20	8.16	
Correct answers after exercise	Active	10	37.30	1.57	0.002*
	Inactive	10	34.60	6.65	

4.2 Heart Rate

The following section is about the analysis of HR before and after exercise for physically active and physically inactive groups.

4.2.1 Heart rate before physical activity for the two groups. The heart rates of both groups before exercise (during resting state) are illustrated in Figure 26. The inactive group exhibited a slightly higher mean heart rate than the physically active group.

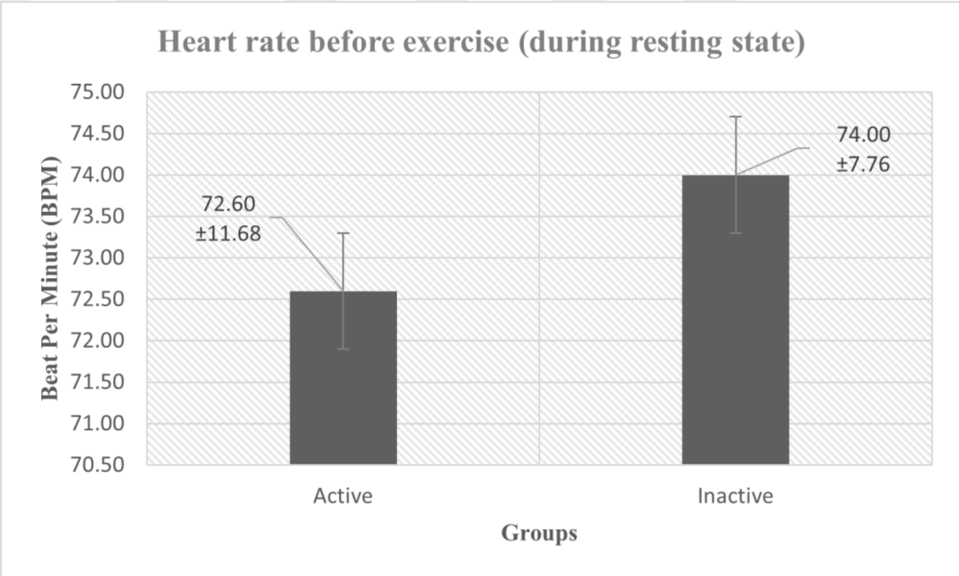


Figure 26. Heart rate measurements before exercise for both physically active and inactive groups.

However, there was no significant difference between the two groups in the heart rate measurement values before exercise during the resting state (Table 7).

Table 7.

Level of significance for Heart rate measurement for both groups before exercise.

	Group	N	Mean	Std.	p = 0.05
Heart rate before exercise (BPM)	Active	10	72.60	11.68	0.210
	Inactive	10	74.00	7.76	

4.2.2 Heart rate after physical activity for the two groups. As expected, the heart rates of both groups increased significantly after exercise (running for 1.6 kilometers), as illustrated in Figure 25. The heart rate measurements of the inactive group were significantly higher than those of the physically active group.

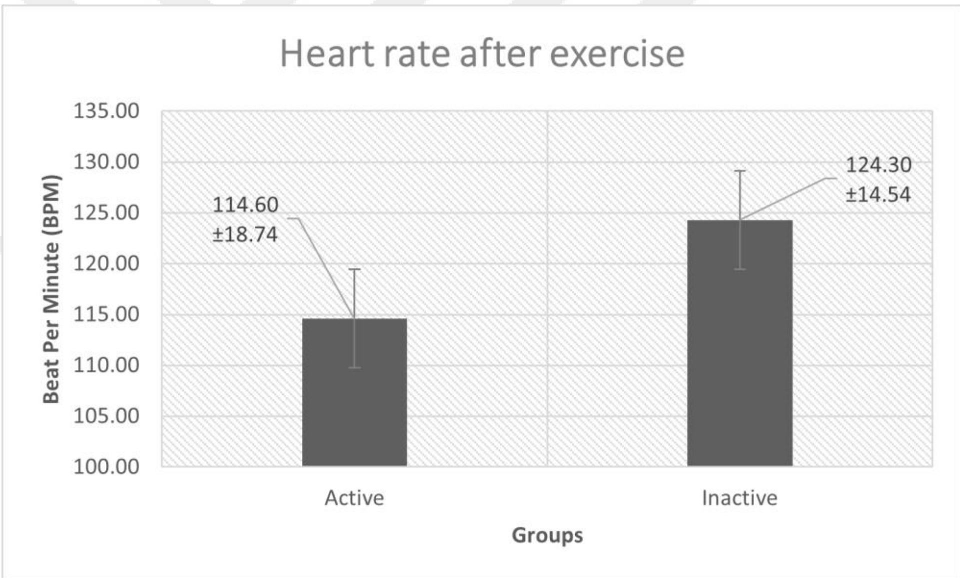


Figure 27. Heart rate measurement after exercise for both groups.

As seen in Table 8, the heart rate measurement after exercise has shown no significant differences with to a p-value higher than 0.05.

Table 8.

Level of significance for Heart rate measurement for both groups after exercise.

	Group	N	Mean	Std.	p = 0.05
Heart rate after exercise (BPM)	Active	10	114.60	18.74	0.311
	Inactive	10	124.30	14.54	

4.3 Stroop Test Average Response Time

The following section is about the analysis of the Stroop test's average time of responding to the questions during the test before and after exercise for physically active and physically Inactive groups. This section is one of two sections needed to determine the attention level of the groups.

4.3.1 Stroop test average response time before exercise. The Stroop effect is a measure of the average response time of the participants during a Stroop test. It measures the average response time of a participant to each stimulus (congruent and incongruent words). The lower the value, the higher the speed the participant took during the test.

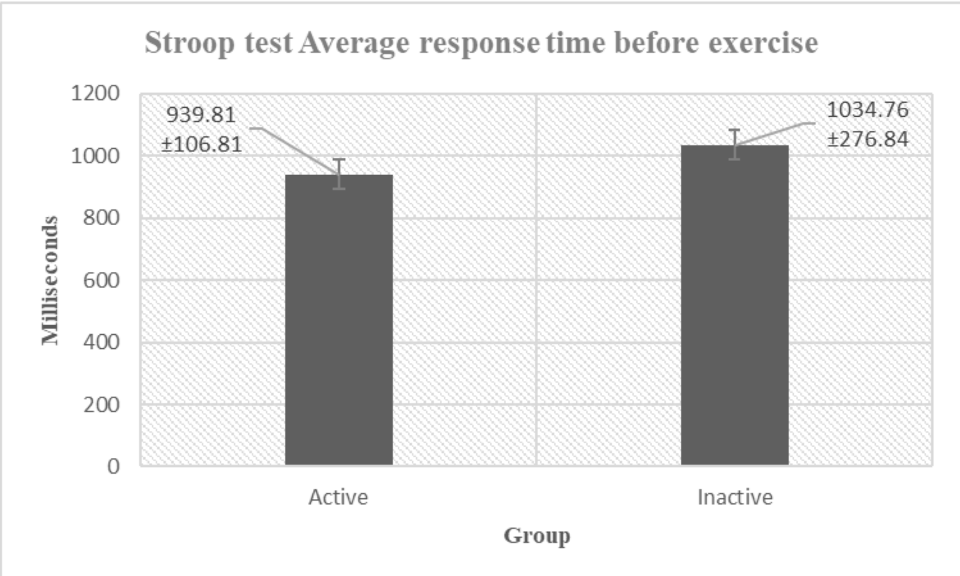


Figure 28. Stroop test average response time (ms) for both groups before exercise.

As illustrated in Figure 28, the physically active group showed a reduced average time to respond compared to the inactive group. This indicates that the physically active group responded to stimuli in the Stroop test at a quicker rate than the inactive group. There is a significant difference ($p<0.05$) between the average response times of the two groups during Stroop test trial recordings (Table 9).

Table 9.

Level of significance for Stroop test Average response time before exercise (ms).

	Group	N	Mean	Std.	p = 0.05
Stroop test average response time before exercise (ms)	Active	10	939.81	106.81	0.013*
	Inactive	10	1034.76	276.84	

4.3.2 Stroop test Average response time after exercise. To determine the Stroop effect, which assesses the average time required for participants to respond to a stimulus (congruent and incongruent words), the average time taken by each participant is calculated. As the value decreased, the participant's speed during the Stroop test increased.

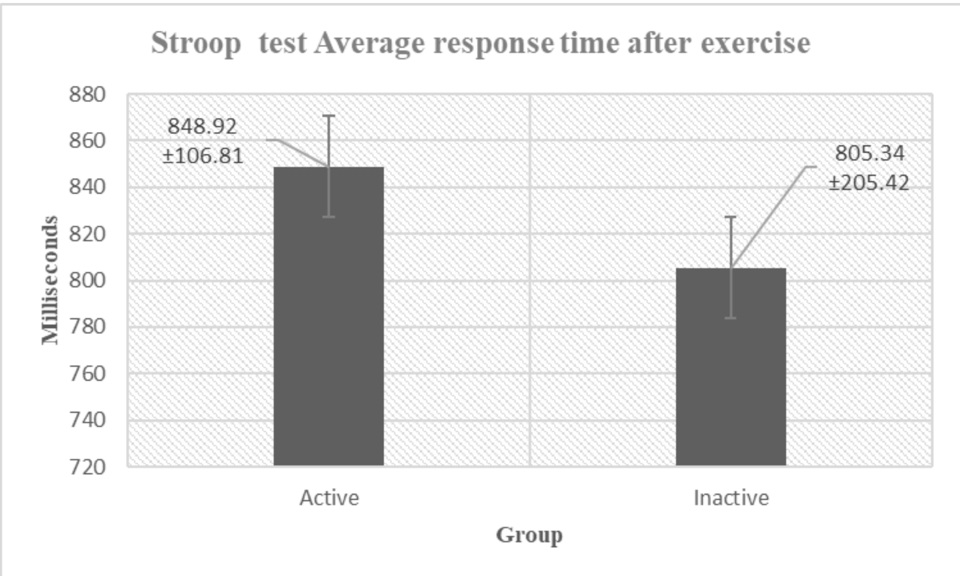


Figure 29. Stroop test average response time (ms) for both groups after exercise.

After exercise, both groups responded to the stimuli at a faster rate, as indicated by the shorter average response time to stimuli in the Stroop test (Figure 29). The physically inactive group demonstrated a greater decrease in response time to stimuli, surpassing the speed of the physically active group. In comparison to the inactive group, the physically active group exhibited a lesser increase following exercise. This may be because the inactive group requires a lower level of activity to remain awake and alert compared to the physically active group, which is capable of running for 1.6 km with ease. There is no significant difference between the average time responses of the two groups after exercise ($p>0.05$).

Table 10.

Level of significance for Stroop test Average response time after exercise (ms).

	Group	N	Mean	Std.	p = 0.05
Stroop test Average response time after exercise (ms)	Active	10	848.92	142.34	0.693
	Inactive	10	805.34	205.42	

4.4 Correct Answers

The following section is about the analysis of the number of correct answers before and after exercise for physically active and physically inactive groups. This section represents the second test to measure the attention level of each group.

4.4.1 Correct answers before exercise. Figure 30 represents the number of correct answers in the Stroop test in both physically active and physically inactive groups before exercise.

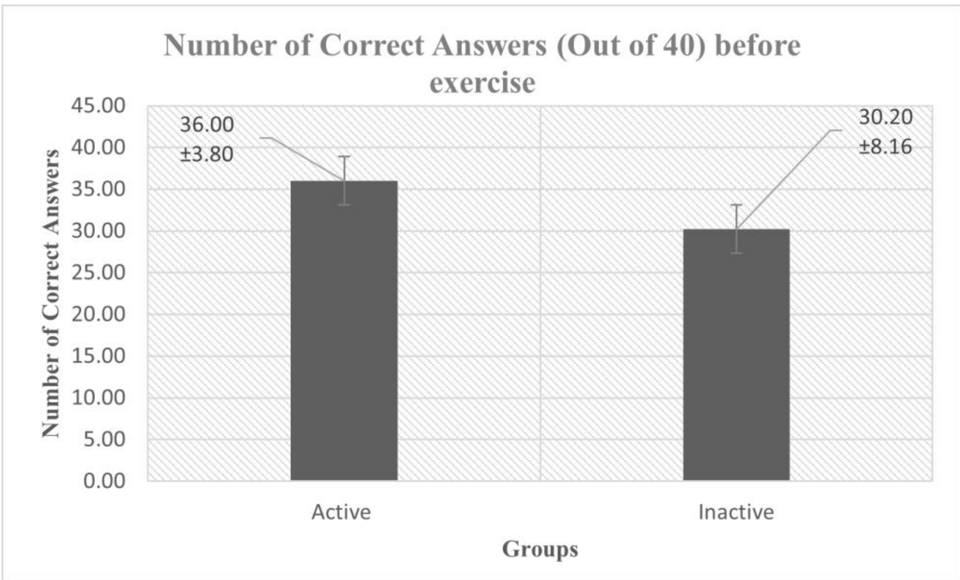


Figure 30. The number of correct answers before exercise (during resting state) for both groups.

As shown in Figure 30, the number of correct answers before exercise is greater in the physically active group compared to the inactive group. It was seen that the physically active group responded to stimuli more quickly and with a greater number of correct answers, indicating a greater level of attention in comparison to the inactive group. There was no significant difference between the two groups in the number of correct answers before exercise during the resting state ($p<0.05$).

Table 11.

Level of significance for correct answers before exercise.

	Group	N	Mean	Std.	p = 0.05
Correct answers before exercise	Active	10	36.00	3.80	0.055
	Inactive	10	30.20	8.16	

4.4.2 Correct answers after exercise. Figure 31 compares the number of correct answers in the Stroop test in both physically active and physically inactive groups after exercise.

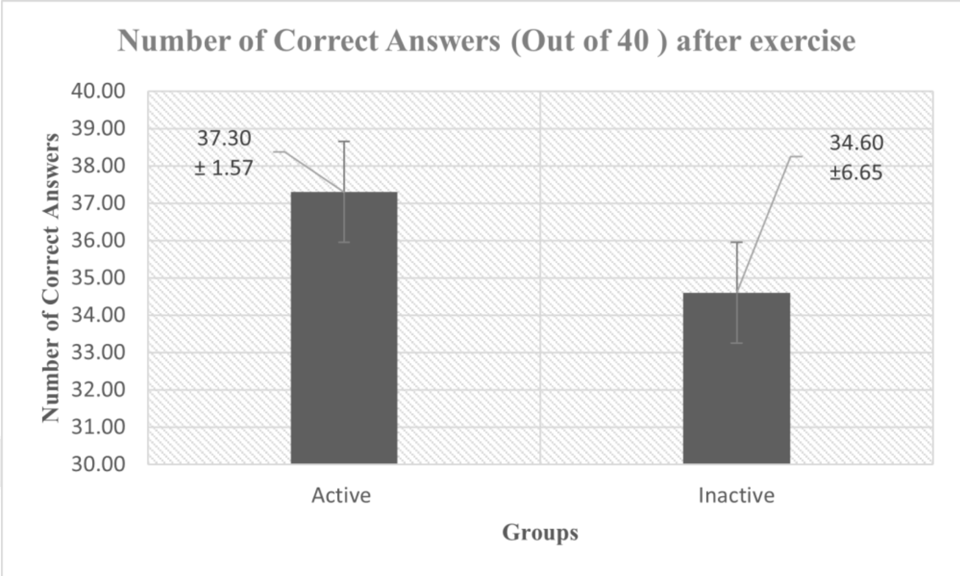


Figure 31. The number of correct answers after exercise for both groups.

Both groups demonstrated an increase in the average magnitude of correct answers after exercise as shown in Figure 31. The physically inactive group experienced a higher increase than the physically active group, as their resting state was 30.20 and increased to 34.60 after exercise. The physically active group experienced a minor increase of 1.3 points, rising from 36.00 at rest to 37.30. This may be due to the level of activity required for a physically active group to achieve wakefulness and alertness, as stated in the previous section. The number of correct answers after exercise had a significant difference between the two groups, as the p-value equals 0.002, which is lower than 0.05, as seen in Table 12.

Table 12.

Level of significance for correct answers after exercise.

	Group	N	Mean	Std.	p = 0.05
Correct answers after exercise	Active	10	37.30	1.57	0.002*
	Inactive	10	34.60	6.65	

4.5 Power Spectrum (μV^2) and Scalp Map Before Exercise Eyes-closed Trial (BEEC)

In Table 1 of the Appendix, the mean power of brain waves was shown for the two groups, one engaged in physical activity and another physically inactive, both with closed eyes. The following summaries encapsulate the key findings across different frequency bands:

Alpha Band: The Alpha band, indicative of a relaxed state of consciousness and situated in the occipital and parietal lobes, exhibited dominance in all electrodes for the physically Inactive group during the trial. A specific instance of this dominance was observed in electrode P3 (35.03 μV^2, P = 0.02, Eta = 0.53).

Beta Band: Associated with active thinking and located in frontal and central regions, the Beta band demonstrated higher amplitudes in the physically Inactive group. Notably, two electrodes (O2, Oz) exhibited higher values in the physically active group (Oz: 20.50 μV^2, P = 0.996, Eta = 0.001; O2: 16.42 μV^2, P = 0.79, Eta = 0.07).

Gamma Band: Responsible for problem-solving and concentration, the Gamma band showed higher amplitude in physically active group electrodes (P3, P8, P4, Oz, and O2) compared to three electrodes (P7, Pz, and O1) in the physically Inactive group.

Theta Band: Dominant in the Inactive group, the Theta band, associated with a relaxed state of meditation and found in frontal, parietal, and temporal lobes, exhibited higher amplitude across five electrodes (P3, Pz, P8, P4, O1, and O2). In contrast, the physically active group showed higher values in electrodes P7 and Oz.

Delta Band: Observed during deep sleep and located in the central cerebrum and parietal lobes, the Delta band demonstrated higher activity in four electrodes. Specifically, the physically active group exhibited higher activity in electrodes P7, Pz, P8, and O1, while the physically Inactive group displayed higher activity in electrodes P3, P4, Oz, and O2.

These findings reveal distinctive patterns of brain wave activity between physically active and Inactive groups during the closed eyes trial, contributing valuable insights to our understanding of cognitive states in different physical activity contexts.

4.5.1 Scalp map for the physically active and physically inactive groups during eyes-closed trial (BEEC) before exercise. Figure 32 represents the scalp map on the left for the physically active group during before exercise eyes-closed trial while representing the power spectrum for the physically active group during before exercise eyes-closed trial on the right.

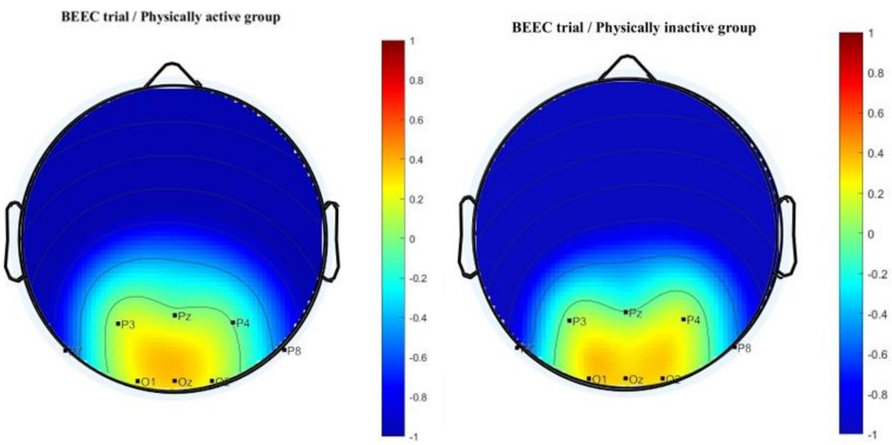


Figure 32. Scalp map for physically active and physically inactive participants during the before-exercise eyes-closed trial.

The voltage values for both groups (physically active and physically inactive) can be seen on the scale voltage maps shown above; positive values are coloured by red and negative values are coloured blue. Both voltage scalp maps demonstrate tangential orientation. The frontal and temporal regions of the brain include areas of negativity that are relatively well-circumscribed, while the parietal occipital region demonstrates positivity that is widely distributed and has a low amplitude. In the physically active group, the maximum voltage values are close to Oz, whereas in the physically Inactive group, O1 and O2 are close to the maximum voltage values.

4.5.2 Power spectrum for the physically active and physically inactive groups during eyes-closed (BEEC) before exercise. The participants maintained a state of mental clarity, composure, and stability for three minutes during the first phase of the experiment, namely the “before-exercise eyes-closed” session. The average power spectrum for both groups is mentioned below (Table 13).

Table 13.

Frequency Bands with their Power Spectrum Magnitude during Before Exercise Eyes-closed (BEEC) Trial for the Physically Active and Physically Inactive groups

Frequency band	Frequency range (Hz)	Group	Power spectrum Magnitude (μV^2)
Delta (δ)	1-4	Physically active	31.94
		Physically inactive	32.10
Theta (θ)	4-8	Physically active	27.27
		Physically inactive	28.05
Alpha (α)	8-13	Physically active	28.01
		Physically inactive	29.86
Beta (β)	13-30	Physically active	21.01
		Physically inactive	21.53
Gamma (γ)	30-60	Physically active	7.00
		Physically inactive	6.89

The power spectrum analysis of the physically active group has shown important indications of a state of mental peacefulness and relaxation. The Delta band, which could be seen between 1 and 4 Hz, demonstrated the most powerful spectrum at 31.94 μV^2, with the Alpha band following at 28.01 μV^2 and the Theta band at 27.27 μV^2. On the contrary, the activity level of the Beta band, which is linked to alertness and concentration, was comparatively lower than that of the other three bands. Furthermore, the gamma band, which is commonly associated with frequencies higher than 30 Hz and is accountable for more complex cognitive processes, demonstrated a diminished magnitude. These might be considered as the outcomes of the participants being in an isolated environment and a state of peacefulness and rest.

The power spectrum of the physically inactive group during the initial phase of the before-exercise eyes-closed trial exhibited distinct patterns, as shown in Table 13 above. It is worth mentioning that the Delta band within the frequency range of 1-4 Hz, exhibits the greatest power spectrum at 32.10 μV^2. Significant slow-wave activity, which is linked to intense relaxation, is indicated by this. The Alpha band (29.86 μV^2) and Theta band (28.05 μV^2), suggestive of a state of peacefulness and relaxation in the brain, exhibited proximity to each other.

On the contrary, the Beta band associated with heightened consciousness and concentrated cognitive effort, demonstrates decreased activity in comparison to the three bands that came before it. The Gamma band, which is commonly observed at frequencies exceeding 30 Hz and is associated with more complex cognitive processes, exhibited a reduced amplitude. This decrease agrees with the participants' overall state of relaxation and peacefulness while in an isolated setting.

A comparative analysis of frequency bands, excluding the Gamma waves, reveals that the physically active group exhibits greater amplitudes in the power spectrum. The activation levels of the occipital, parietal, and posterior temporal lobes are notably elevated. The observed neural response indicates that distinct brain wave patterns occur during this initial stage, specifically in areas linked to attention and sensory processing.

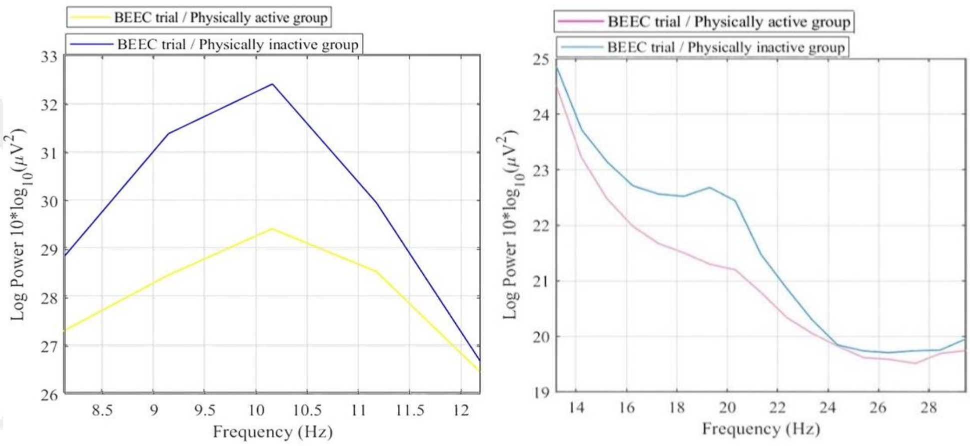


Figure 33. The power spectrum for alpha and beta bands during the before-exercise eyes-closed trial.

The research mainly focused on the Alpha and Beta frequency ranges; consequently, Figure 33 illustrates the power spectrum for both groups within this range. The results of this trial indicate that the physically inactive group exhibited higher values in the Alpha and Beta frequency ranges compared to the physically active group. This finding suggests that the physically inactive group experienced greater levels of alertness and relaxation during the eyes-closed restful state (before exercise) than the physically active group.

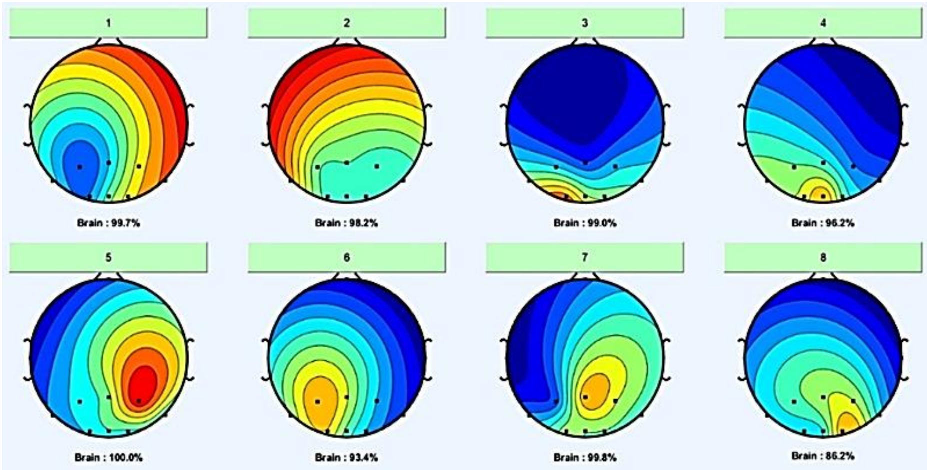


Figure 34. Component properties of physically inactive participants during the before-exercise eyes-closed trials.

The electrodes corresponding to the eyes-closed trials are P3, P7, Pz, P8, P4, O1, Oz, and O2. The presented figure demonstrates that each of the eight electrodes exhibits a substantial proportion of the brain signal acquired throughout the recording procedure. It is seen that the percentage of brain signals collected from these electrodes ranges between 86.2% to 100% which indicates the high value of brain signals compared to other kinds of signals that can be collected during the process of recording for example eye, muscle, and heart signal.

4.6 Power Spectrum and Scalp Map During Before-Exercise Eyes-Open Trial

When comparing the data presented in Tables 2 and 3 in the Appendix, certain trends emerge. In the alpha band, the physically inactive group showed higher amplitude across ten electrodes, while the physically active group exhibited this pattern in six electrodes. While, in beta band, the physically active group had higher amplitude with twelve electrodes, while the physically inactive group showed this trend with four electrodes. The gamma band displayed higher amplitude in the physically active group across eleven electrodes, as opposed to the physically inactive group's five electrodes. Additionally, the physically inactive group dominated in theta band activity across nine electrodes, while the physically active group exhibited this pattern in seven electrodes. In terms of the delta band, the physically inactive group had higher amplitude across eleven electrodes compared to the physically active group's presence in five electrodes.

4.6.1 Scalp map for the physically active and physically inactive groups during eyes-open (BEEO) before exercise. During the second phase of the experiment, participants maintained the same position as in the previous stage (referred to as before the exercise eyes-closed trial) "before exercise eyes-open" trial. The participants were directed to open their eyes and concentrate on a fixed point in a dim and quiet room. With this trial, the Alpha band, associated with a state of wakefulness, maintained its elevated state. In contrast, the Beta band, which is associated with increased cognitive processes and attentive wakefulness in the frontal and central regions, plays a part in intense mental activity.

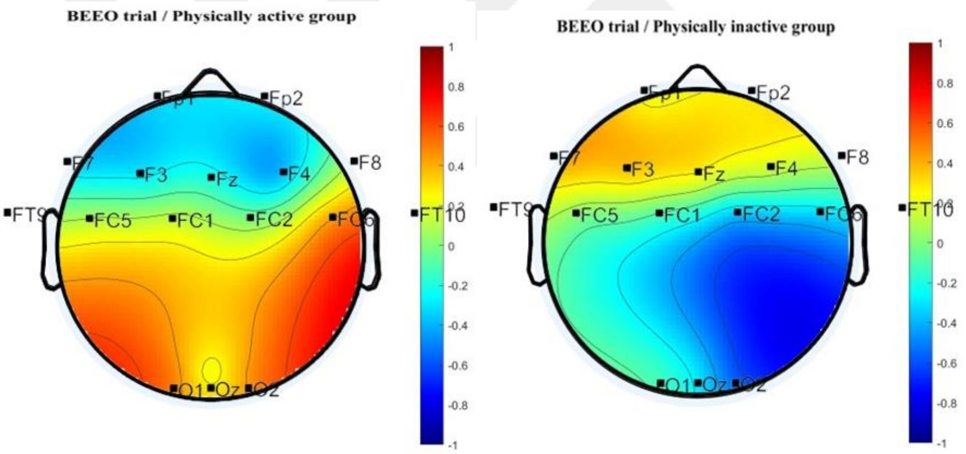


Figure 35. Scalp map for physically active group and physically inactive group before exercise eye-open trial.

As shown above, the scalp voltage map of the eye-open trial before exercise for both groups show the activation of brain regions with blue and red colors, respectively, corresponding to negative and positive magnitudes of voltage. The results indicate that the physically active group exhibits tangential orientation, with negative values highest in the frontal regions of the brain (as indicated by the maximum negative value on the F4 electrode). Decreasing negativity is then observed within regions covering the parietal, occipital, and major parts of the temporal lobes, which have positive values. The temporal regions of the brain showed the greatest positive activation in this trial (FC6, O1, and O2 had the highest positive values).

The scalp map of the physically inactive group showed a temporal-polar orientation. It is observed that the posterior region of the right temporal region, as well as the right regions of the central, parietal, and occipital lobes of the brain, show the highest negativity values (the O2 electrode recorded the maximum negative value). Following that, the negative value began decreasing in the left temporal and anterior central regions of the brain. The regions representing positive values are the frontal and anterior regions of the temporal lobes, while the left anterior region of the temporal lobe shows the highest positive activation, as indicated by the Fz and F3 electrodes.

4.6.2 Power spectrum for the physically active and physically inactive groups during eyes-open (BEEO) trial before exercise. Before the eyes-open trial, which represents the second phase of the experiment, the participants maintained mental stability, composure, and focus for three minutes on a fixed point in a dim and quiet environment. The following table presents the average power spectrum for both statuses.

Table 14.

Frequency bands with their power spectrum magnitude in before exercise eyes-open (BEEO) trial for the physically active and physically inactive groups

Frequency band	Frequency range (Hz)	Group	Power spectrum Magnitude (μV^2)
Delta (δ)	1-4	Physically active	30.34
		Physically inactive	30.52
Theta (θ)	4-8	Physically active	25.50
		Physically inactive	25.53
Alpha (α)	8-13	Physically active	24.54
		Physically inactive	24.79
Beta (β)	13-30	Physically active	20.73
		Physically inactive	19.63
Gamma (γ)	30-60	Physically active	4.92
		Physically inactive	3.69

For the physically active group, the power spectrum is shown in the table above. The average power spectrum magnitude of the Delta band was found to be 30.34 μV^2, with the Alpha band following at 24.54 μV^2 and the Theta band at 25.50 μV^2. The mean magnitude of the beta band was 20.73 μV^2. It is noteworthy that the amplitudes of the Theta band exhibited a decrease as the trials switched from eyes-closed conditions (27.27 μV^2) to eyes-open conditions (25.50 μV^2). Likewise, there was a reduction in the amplitude of the Alpha band when comparing eyes-closed (28.01 μV^2) to eyes-open (24.54 μV^2) conditions. The observed variations in amplitude indicate variations in neural activity across the various visual conditions, thereby offering significant insight into the cognitive processes that were operational throughout the experiment.

The observations of the physically inactive group data have shown that there was a decrease in the alpha band from 29.86 μV^2 during the resting state eyes-closed trial to 24.79 μV^2 when the eyes were open. Similarly, there was a decrease in both the beta and gamma bands, respectively from 21.53μV^2 to 19.63μV^2 and 6.89μV^2 to 3.89μV^2.

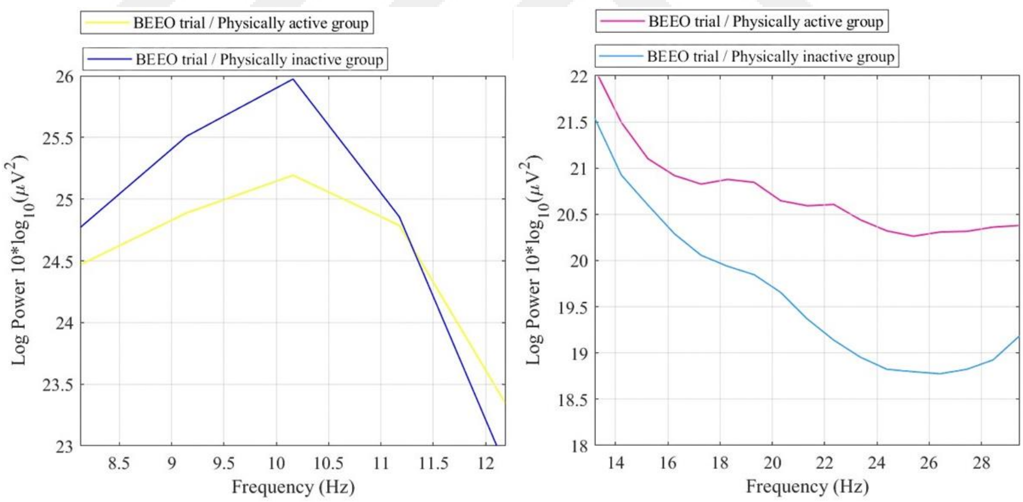


Figure 36. Power spectrum for Alpha and Beta bands during before-exercise eyes-open trial.

Due to the fact that the study focused particularly on alpha and beta bands, the changes of these waves were shown in Figure 36 above. The physically inactive group showed a higher alpha band peak, whereas the physically active group showed a higher beta band peak. This might have been due to the fact that participants who were not physically active exhibited a greater degree of relaxation than those who were physically active. Conversely, the physically active group demonstrated a greater degree of alertness compared to the physically inactive group.

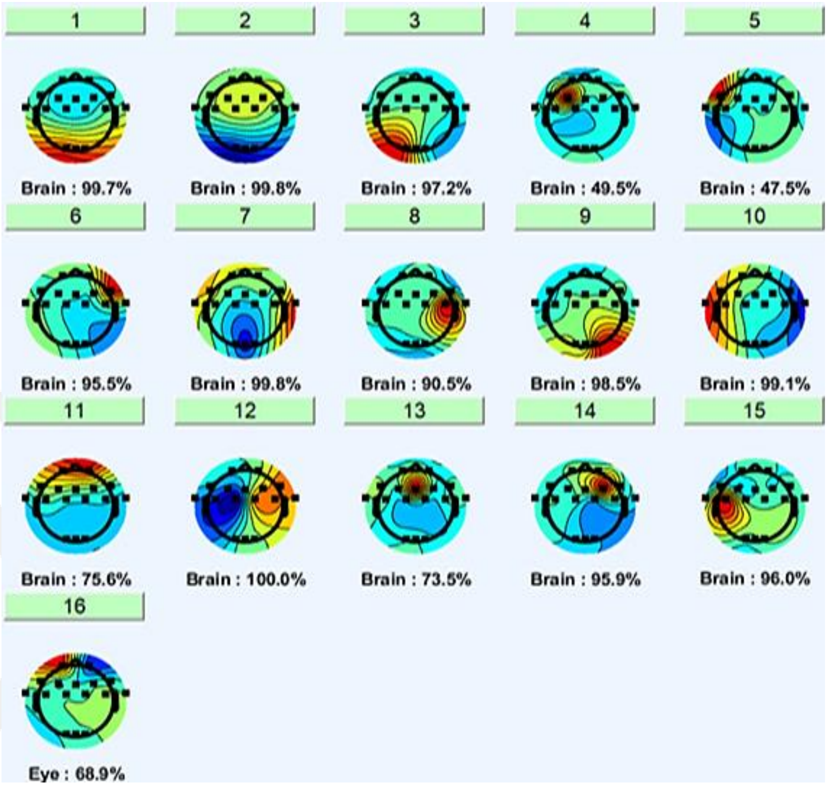


Figure 37. Component properties of the eyes open for physically inactive participants.

The electrodes that EEG data were measured were Fz, Fp1, F7, F3, FC1, FC5, FT9, FC6, FC2, FT10, F4, F8, Fp2, O1, Oz, O2. The percentage of brain signals collected through the recording process for eleven electrodes was between 90.5% and 100% which indicates that most of the signals collected were brain signals. Four electrodes have a percentage of brain signal ranging between 47.5 and 75.6 which might indicate that there are other sources of signals in the recordings, however brain signals dominate the data collected. Only one electrode has an eye-dominant signal. These values are normal since during this process eyes were open and participants kept looking at a fixed point which caused more signals to be collected during the process than the eyes-closed trials.

4.7 Power Spectrum and Scalp Map during Stroop test trial for physically active group and physically inactive group.

Before the exercise Stroop test trial, the alpha band dominance was observed in the physically inactive group across nine electrodes, surpassing the physically active group's seven electrodes. On the other hand, the physically active group dominated the beta band with ten electrodes compared to the physically inactive group's six electrodes. Gamma band dominance was noted in the physically inactive group across eleven electrodes, while the physically active group exhibited this in five electrodes. Theta and delta bands were dominant in the physically active group, with the former having twelve electrodes and the latter displaying higher amplitude in nine electrodes.

After exercise, Stroop test trial revealed that the physically active group showed dominance in the alpha, theta, and delta bands. Conversely, the physically inactive group exhibited dominance in the gamma band. The beta band had an equal number of electrodes in both groups. The physically active group displayed higher amplitudes in the beta band across certain electrodes compared to the physically inactive group. Notably, the physically active group showed significantly increased amplitude in the gamma band in specific electrodes. In the theta band, the physically inactive group had higher amplitudes in certain electrodes. In the delta band, certain electrodes in the physically inactive group exhibited larger amplitude than the physically active group.

4.7.1 Scalp map for the physically active group during Stroop test. During the resting part of the experiment before exercising, the third trial involved the administration of the Stroop test, specifically focusing on the colour/word type. The participants maintained a stationary position during the recordings exhibiting minimal movement except that the response to the stimuli during the test. Specifically, the participants were allowed to only move their fingers in a single action, namely pressing the button, while refraining from blinking or engaging in any other form of movement.

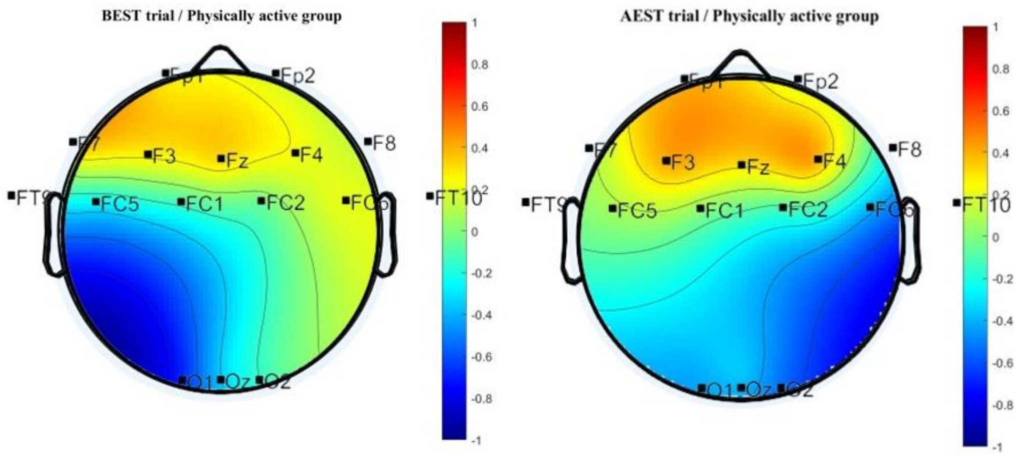


Figure 38. Scalp map for physically active group during Stroop test before and after exercise.

The cognitive task recording trial was done for the physically active group both before and after the exercise. Both scalp voltage maps showed higher positive activation in the frontal and anterior regions of the temporal lobes of the brain, respectively. It was observed that the right temporal lobe exhibited a greater spectrum of activation compared to the frontal and anterior regions of the left temporal lobes for the maps of participants before exercise during the Stroop test recordings. It is observed that the anterior lobe and anterior regions of the left temporal lobe exhibited the highest degree of positive activation (maximum at F7 and Fz). The posterior region of the left temporal lobe and the left region of the occipital region showed negative voltage values, which afterward started decreasing (the O1 electrode recorded the maximum value).

A greater intensity of positivity has been observed in the frontal and anterior regions of the temporal lobes after exercise as indicated by the maximal values recorded on the Fp1, F3, and F4 electrodes. The negative voltage value showed a shift towards higher values in the posterior region of the right temporal lobe, right parietal, and occipital regions of the brain. It was then followed by a decrease in value towards the left side of the brain (including the left temporal, parietal, and occipital regions), which was lower than the negative values in the right regions (the maximum negative value recorded in electrodes FT10, FC6, and O2).

4.7.2 Power spectrum for the physically active group during Stroop test. During the Stroop test trials, which included the third and fourth phases of the experiment, participants were required to complete a cognitive task consisting of 40 words both before and after the exercise. This particular phase had a maximum duration of 80 seconds. The mean power spectrum for both experiments is presented in Table 15.

Table 15.

Frequency Bands with their Power Spectrum Magnitude in Before and After Exercise Stroop Test Trials for the Physically Active Group.

Frequency band	Frequency range (Hz)	Status	Power spectrum Magnitude (μV^2)
Delta (δ)	1-4	Before exercise Stroop test	30.88
		After exercise Stroop test	30.97
Theta (θ)	4-8	Before exercise Stroop test	25.85
		After exercise Stroop test	26.06
Alpha (α)	8-13	Before exercise Stroop test	23.31
		After exercise Stroop test	23.79
Beta (β)	13-30	Before exercise Stroop test	20.17
		After exercise Stroop test	20.50
Gamma (γ)	30-60	Before exercise Stroop test	4.42
		After exercise Stroop test	4.89

Table 15 shows that the average magnitude of the frequency band for the same group changed between before exercise and after exercise. It is observed that the average magnitude of the five frequency bands has increased after exercise, suggesting that the level of activation in these regions has risen. This might indicate that the subjects were more attentive and more focused when responding to stimuli and that they were more relaxed as well.

Table 16.

Stroop task performance results for the physically active group.

	Congruent Response time (ms)	Incongruent Response time (ms)	Accuracy (%) Incongruent
Before exercise	815.89 ±135.46	980.87 ±109.90	91.75
After exercise	784.90 ±168.80	869.03 ±143.99	95.25

The data for the time response and accuracy percentage of the incongruent stimulus-response are presented in Table 16. Both the average response time and the accuracy percentage were found to increase after exercise. These values indicate that the level of attention of the participants was increased after exercise.

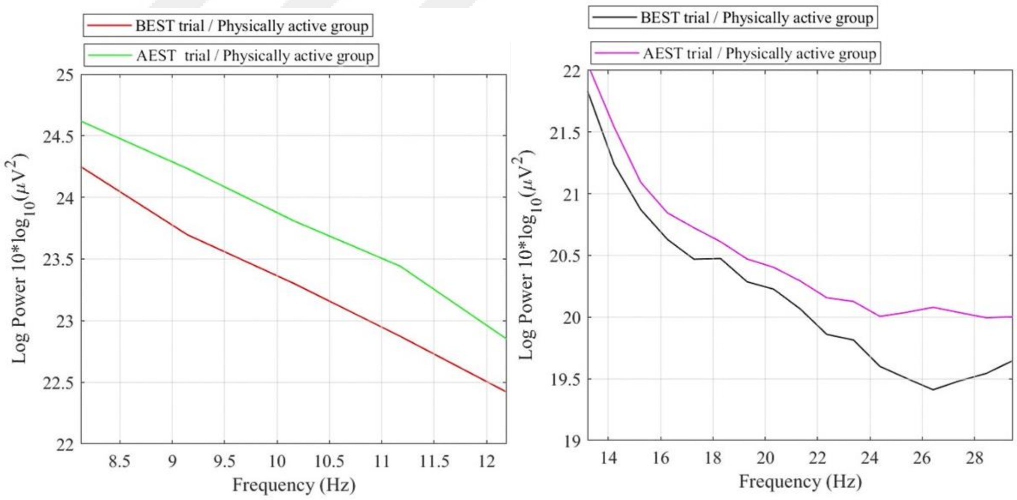


Figure 39. The power spectrum for Alpha and Beta bands before and after exercise Stroop test trials for the physically active group.

Figure 39 represents the power spectrum of the Alpha and Beta bands during the “before and after exercise” Stroop test trials. It is examined that the power of both Alpha and Beta increased after exercise. This could be due to the physically active group experiencing improved levels of alertness and relaxation after exercise. Physical activity might have increased the alertness and relaxation of the participants which might be aligned with the findings of the previous study and the hypothesis of this study.

4.7.3 Scalp map for the physically inactive group during Stroop test. Figure 40 represents the voltage maps taken during the Stroop test before and after exercise. The subject remained in the same state throughout the recording, except for responding to the observations.

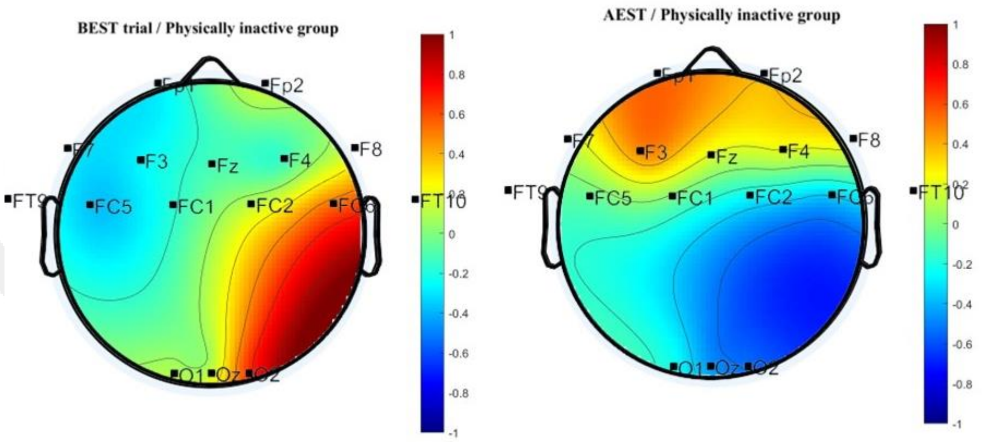


Figure 40. Scalp map for physically inactive group during Stroop test before and after exercise.

The scale voltage map in the physically inactive group before and after exercise is represented in Figure 40 above, showing positive and negative activation values. For the physically inactive group during the resting state (before exercise) voltage map showed a temporal-polar orientation with a higher positive voltage value on the posterior region of the right temporal lobes (maximum FC6 and O2). The positive value started decreasing until it reached the negative voltage value in the anterior region of the left temporal lobe (the maximum value recorded for the negative voltage value from the FC5 electrode). After exercise, the scalp voltage map showed a temporal-polar orientation. In this voltage map, the negative voltage value moved to the posterior region of the right temporal lobe and part of the occipital, central, and parietal regions of the brain (maximum negative values were recorded using Oz and P2 electrodes). The negativity starts to decrease until it reaches the frontal and anterior regions of the temporal lobes, which represent the positive voltage values represented by the red and yellow colors (maximum positive values recoded using the FP1 and F3 electrodes).

4.7.4 Power spectrum for the physically inactive group during the Stroop test. Participants in the third and fourth phases of the experiments were instructed to perform the cognitive task represented by the Stroop test before and after engaging in the physical activity. The physically inactive group responded to the forty words, which contained both congruent and incongruent words, in a maximum of eighty seconds. As illustrated below, the frequency ranges undergo variations during this phase according to the participants' statuses.

Table 17.

Frequency Bands with their Power Spectrum Magnitude in Before and After Exercise Stroop Test Trials for the Physically Inactive Group

Frequency band	Frequency range (Hz)	Status	Power spectrum Magnitude (μV^2)
Delta (δ)	1-4	Before exercise Stroop test	30.81
		After exercise Stroop test	30.50
Theta (θ)	4-8	Before exercise Stroop test	25.56
		After exercise Stroop test	26.64
Alpha (α)	8-13	Before exercise Stroop test	23.61
		After exercise Stroop test	24.02
Beta (β)	13-30	Before exercise Stroop test	20.04
		After exercise Stroop test	20.62
Gamma (γ)	30-60	Before exercise Stroop test	4.96
		After exercise Stroop test	6.24

Table 17 shows that the physically inactive group had an increase in four of the frequencies out of five after exercising. Other than the delta band, which showed a decrease from 30.81 μV^2 to 30.50 μV^2 after exercise, had an increase in the level of brain activation after physical activity. In other words, exercise has increased the level of attention.

Table 18.

Stroop task performance results for physically inactive group

	Congruent Response time (ms)	Incongruent Response time (ms)	Accuracy (%) Incongruent
Before exercise	969.17 ±296.09	1056.50 ±272.24	81
After exercise	760.84 ±171.95	820.77 ±225.86	91

The accuracy percentages for incongruent words and the response times for both congruent and incongruent cases of the Stroop test are given in Table 18. The parameters previously mentioned were used again as indicators to determine the attention level, as shown by the decrease in average response time and increase in accuracy percentage. This indicates an increase in the percentage of positively responding to incongruent words at a faster rate (in less time); in other words, the physically inactive group's attention level has increased after exercise.

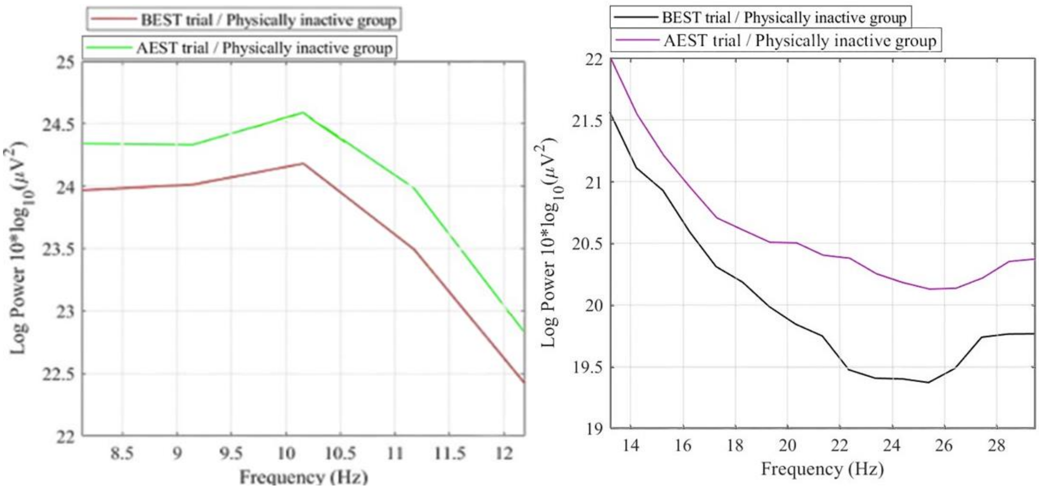


Figure 41. Power spectrum for Alpha and Beta bands during before and after exercise Stroop test trials for physically inactive groups.

The figure above shows the alpha and beta bands seen in the physically inactive group during the Stroop test trials before and after exercise. Both alpha and beta increased after exercise, indicating that the participants experienced increased wakefulness and relaxation during the after-exercise test recordings.

4.8 Percentage Change for Stroop test trial for Physically active and physically inactive groups.

Table 4 in the Appendix represents the percentage changes in two conditions (before-exercise Stroop test and after-exercise Stroop test) for both physically active and inactive groups. The findings reveal that, in the after-exercise Stroop test, the physically active group demonstrated a higher percentage increase for nine electrodes, while three electrodes had equal changes in magnitude between the two trials, and four electrodes exhibited greater magnitudes during the before-exercise Stroop test.

Specifically, in the Alpha band, the physically active group showed the largest percentage change in electrode O2, located in the occipital region, with an 18% higher magnitude in the after-exercise Stroop test. In contrast, the physically inactive group had higher magnitudes for ten electrodes during the after-exercise Stroop test, with FC5 in the left temporal region showing the highest difference percentage of 9%.

In the Beta band frequency range the physically active group had higher magnitudes in eleven electrodes during the after-exercise Stroop test, with O2 in the occipital region displaying the highest difference percentage of 31%. Meanwhile, the physically inactive group showed higher magnitudes in eleven electrodes, with O2 having the largest difference in magnitude at -16%, indicating a higher magnitude in the Before exercise Stroop test.

In the Gamma band, the physically active group exhibited positive magnitudes in nine electrodes, while the physically Inactive group had twelve positive magnitudes. Notably, the F8 electrode in the right temporal anterior MID scalp had the highest difference percentage in the physically active group (+142%), while the Oz electrode had the highest differential percentage magnitude in the physically Inactive group (+109%).

In the Theta band, the physically active group displayed positive magnitudes in seven electrodes, with Oz having the highest difference percentage at -9%. In contrast, the physically Inactive group showed positive values in four electrodes, and Oz had the highest percentage difference with a magnitude of -14%.

In the Delta band, the physically active group had six positive magnitudes, with Oz displaying the highest difference percentage of +29%. The physically Inactive group had only two positive magnitudes, and F4 had equal magnitudes in both trials, while most electrodes (thirteen) exhibited negative magnitudes, indicating higher magnitudes during the Before exercise Stroop test trial.

In summary, the findings highlight that the alpha band in the physically active group experienced greater changes in mean absolute power, particularly in electrode F7 with a 7% increase. Additionally, the beta band in the physically Inactive group exhibited greater mean absolute power, notably in electrode Fz with a 12% increase.

Figure 42 represents the precise placement of each electrode in the brain, along with the corresponding anatomical name of each region.

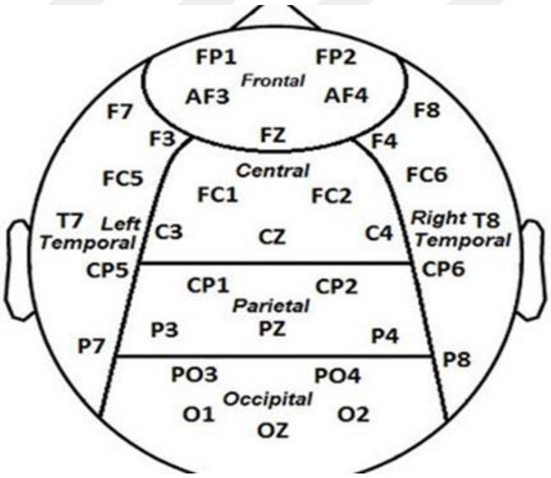


Figure 42. Electrode's location in the brain (Kora, Meenakshi, Swaraja, Rajani & Raju, 2021).

Chapter 5

Discussions and Conclusions

This chapter includes a discussion of the findings represented in chapter four, answering the research questions the researcher seeks to find.

5.1 Discussion

Placing the study within the broader context of the Biomedical Engineering field, the findings presented in this thesis might contribute to the understanding of the impact of physical activity on the neurophysiological markers of attention and heart rate. Exercise has been documented to improve cognitive functions including attention and improve cardiac functions as well.

The first question addressed in this study focused on determining the attention levels between physically active and physically inactive groups. The results indicated a significant difference, with a higher level of attention observed in the physically active group. This was evident from their higher Stroop effect even before engaging in any physical exercise. These findings align with a previous study by Meng, Xie, Qiu, Geng & Li (2022) that investigated attention levels in young adults, particularly college students. The results of our study correspond to theirs, suggesting that being physically active enhances attention levels. Additionally, another study by Putri, Puruhito, Pramono & Kumaidah (2020) found that six weeks of exercise increased attention levels in young individuals, supporting the study's findings that physically active individuals tend to have higher attention levels.

The second question in this study explored whether there was any change in attention levels after engaging in physical exercise. Surprisingly, the findings revealed an increase in attention levels while answering the test for both groups, reaching a similar level of attention. This outcome contrasts with the findings of Llorens, Sanabria & Huertas (2015), who reported a reduction in attention levels for physically inactive individuals, or as they termed them, "low fit," after engaging in physical exercise. Notably, in our study, both groups participated in a 6–10 minutes run covering a distance of 1.6 km, and both demonstrated an increase in attention levels, particularly the Inactive group.

During the study, the comparison of the number of correct answers between the two groups before engaging in physical exercise revealed no significant difference, despite after the exercise, which revealed a significant difference between the two groups' number of correct answers .

Examining Table 4 and 5, it is evident that after physical exercise, the Stroop effect and the number of correct answers increased in both groups, indicating an improvement in attention levels after exercise.

During the standard EEG trials (Before-exercise eyes-closed / Before-exercise eyes-open) in both groups, the ALPHA band exhibited its highest values during the eyes-closed trial and decreased during the eyes-open trial. Similarly, the BETA band showed a decrease through the eyes-open trial, and the power spectrum in the theta, delta, and gamma bands decreased during the eyes-open trial.

When performing the Stroop test in the physically active group, their frequency bands slightly increased after physical exercise, aligning with the findings of Devilbiss et al. (2019) which showed an increase in most frequency bands in male physically active participants after moderate exercise. In contrast, the physically inactive group exhibited a higher level of elevation after physical exercise in all frequency bands except the delta band, which experienced a small reduction in magnitude after physical exercise.

5.2 Conclusion

This research aims to enhance the understanding of how physical activity influences neurophysiological markers, specifically attention. To measure these markers in resting and active states, an Emotive EPOC Flex device was used for EEG signals and pulse oximeters.

Existing literature has consistently highlighted the positive effects of exercise on cognitive function, encompassing attention and cardiac functions. Contrary to expectations, the study revealed no significant difference in heart rate between the two groups. This lack of distinction could be attributed to various lifestyle factors, such as sleep quality, food quality, and a lifestyle characterized by nonsmoking and abstinence from alcohol. These factors influence resting heart rate and may impact the heart rate during the active state, particularly after running for 1.6 km.

The study investigated the attention levels in physically active and inactive groups. Interestingly, physically active individuals exhibited a higher Stroop effect before engaging in physical exercise, aligning with previous studies. After exercise, both groups demonstrated increased attention levels, particularly in the inactive group.

Examining the number of correct answers before and after physical exercise, the number of correct answers before physical exercise showed no significant difference between the two groups, despite after physical exercise, which showed a significant difference. Additionally, the Alpha band reached its peak during EEG trials (Before-exercise eyes-closed / Before-exercise eyes-open) and decreased during the eyes-open trial, while the Beta band decreased throughout the eyes-open trial.

In the Stroop test, the physically active group experienced a slight increase in frequency bands. Conversely, the physically Inactive group displayed higher levels after physical exercise in all frequency bands, except for the delta band, which exhibited a slight reduction in magnitude.

In conclusion, this study underscores the significance of physical activity in enhancing both attention levels providing valuable insights into the complex interplay between physical activity and neurophysiological responses.

5.3 Recommendations

- Measure the ECG, EMG, and EEG between the male and female subjects doing another type of aerobic exercise such as squatting or jumping rope with different cognitive tests such as the Trial Making test.
- Measure the ECG and EEG between the smokers and Nonsmokers physically active doing specific types of aerobic exercise (try to select participants with the same activity level).

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