The Influence of Music on Concentration in Individuals with ADHD

by
Johannes Gysbertus Vorster

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Supervisor: Prof, Pieter Rousseau Fourie
Co-supervisor: Prof, David Jacobus van den Heever
Dr, Melike Fourie

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Declaration

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March 2020

Abstract

The aim of the present study was to determine whether different musical experiences can influence concentration in a positive way. As a result, determining whether music can be used as an alternative management method for attention-deficit hyperactivity disorder (ADHD). A total of 11 volunteers (8 females and 3 males) with a mean age of 21.85 years, diagnosed with ADHD, participated in this study.

Each participant participated in a four-day experiment where they were subjected to a different treatment condition on each day. Specifically, the four conditions consisted of binaural beats, classical music, music of preference, and ADHD medication. To assess performance and concentration, four behavioral tasks (Stroop task, sustained attention task, working memory task as well as time perception task) were introduced during each condition. Functional-near infrared spectroscopy (fNIRS) was used to monitor the prefrontal cortex for changes in oxy-, deoxy-, and total-haemoglobin across all four days.

Analysis of near-infrared spectroscopy data revealed that oxy-haemoglobin induced the greatest activity across the prefrontal cortex. No overall significant differences in activation levels were observed for the four behavioural tasks, however. In terms of the behavioural data, the only significant effect across conditions were observed for the sustained attention task. Here, the medication condition was associated with significantly better performance in comparison to the binaural beats condition. Binaural beats negatively affected performance and increased reaction time during this task.

The results from this study suggest that listening to binaural beats negatively impacts sustained attention in comparison to classical music, music of preference, as well as medication. Although these results are not conclusive, it provides initial evidence that different musical experiences affect attention in different ways, thereby supporting its potential use as an alternative management method for ADHD. The study also provides insight into how the ADHD brain responds to different musical experiences as well as medication.

Uittreksel

Die doel van hierdie studie was om te bepaal of verskillende forms van musiek konsentrasie op 'n positiewe manier kan beinvloed. Die rede waarom daar gekyk word na musiek is om te bepaal of musiek gebruik kan word as 'n alternatiewe manier om aandagafleibaarheid-hiperaktiwiteitsindroom (ADHD) te bestuur. In totaal het 11 vrywilligers (8 vroulik en 3 manlik) met 'n gemiddelde ouderdom van 21.85 jaar gediagnoseer met ADHD deelgeneem aan die studie.

Al die deelnemers was blootgestel aan vier behandelings metodes naamlik: “binaural beats“, klassieke musiek, musiek van individuele keuse en medikasie. Om te bepaal hoe optrede en konsentrasie beinvloed word was vier gedrags toetse gebruik in die studie. Hierdie toetse het bestaan uit 'n Stroop toets, volhouare aandags toets, memorisasie toets sowel as 'n persepsie van tyd toets. Elke deelnemer het deelgeneem aan die experimentele fase wat oor vier dae was. Op elke dag was die deelnemer blootgestel aan 'n ander behandelings metode. Naby-infrarooispektroskopie was gebruik om die prefrontale kortex te monitor vir veranderinge in hemoglobin konsentrasies.

Gedurende die analise het suurstof-hemoglobien groter verskille oor die prefrontale kortex aangedui. Die analise van hemoglobien het nie beduidende verskille aangetoon oor gedrags toetse nie. Die data van gedrags toetse vertel wel 'n ander storie. Gedurende die volhoubare aandags toets was gevind dat medikasie verantwoordelik was vir 'n beduidende verskil in vergelyking met “binaural beats“. Die “binaural beats“ was verantwoordelik vir negatiewe impak op reaksie tyd en het gelei na 'n toename in tyd.

Die resultate van hierdie studie dui daarop aan dat “binaural beats“ verantwoordelik was vir 'n afname in produktiewiteit in vergelyking met klassieke musiek, musiek van individuele keuse en medikasie. Alhowel hierdie resultate nie beduidend is nie dui die aanvanklike resultate dat verskillende forms van musiek konsentrasie affekteer in verskillende maniere. Die genoemde staaf die potensiaal van musiek as 'n moontlike bestuurs metode vir ADHD. Hierdie studie voorsien meer insig op hoe die ADHD brein reagreer op musiek sowel as medikasie.

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Laastens wil ek all eer aan die Hemelse Vader gee vir die talente waarmee hy my geseën het.

To my Parents

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Abbreviations

ADD	Attention Deficit Disorder
ADHD	Attention Deficit Hyperactivity Disorder
ANOVA	Analysis of Variance
DCT	Discrete Cosine Transform
EEG	Electroencephalography
ERP	Event-Related Potentials
HREC	Human Research Ethics Committee
IQ	Intelligence Quotient
MRI	Magnetic Resonance Imaging
MBLL	Modified Beer-Lambert Law
IP	Internet Protocol

1 Introduction

1.1 Background

Attention Deficit Hyperactivity Disorder commonly known as ADHD is a chronic condition characterised by three primary symptoms: impulsivity, inattention, and hyperactivity. The condition is becoming one of the most common neurodevelopmental conditions diagnosed in children as well as adults (Faraone *et al.*, 2015). Management of ADHD usually requires medication, which has its own negative effects on the body as well as on the brain.

Treating ADHD is expensive and therefore not accessible to everyone in South Africa. This project investigates music therapy as a potential cost-effective method for the improvement of concentration. The end goal of the project is to find an alternative management method to assist ADHD individuals.

1.2 Objectives

Music has been demonstrated to have a positive effect on concentration. Listening to music while studying is becoming popular among university students (Statista, 2019). In aiming to understand how music influences the ability to concentrate among ADHD individuals, the following objectives were set:

- To investigate different types of music known to improve concentration and cognitive ability.
- To investigate appropriate neuro-imaging techniques as well as cognitive attention tasks to be implemented in the study.
- To plan and conduct an experiment whereby participants with ADHD will be recruited.
- To analyse results from the experiment in order to determine if a correlation exists between different musical experiences and attention.

1.3 Motivation

It is estimated that one in 20 children, as well as one million adults in South Africa, are affected by ADHD, (Schoeman, Albertyn & de Klerk, 2017). The South African health sector in general is under immense pressure due to the number of people it is expected to serve. If ADHD is untreated it may result in substantial cost and have a negative impact on the quality of life as well as educational attainment. The cost associated with ADHD treatments is another concern as 55.5% of South Africans live in poverty (Statistics South Africa, 2015).

The annual cost for caring for people with ADHD is staggering, ranging from $2 720 (± R36 082.40) for children to $4 120 (± R54 654.23) for adults, according to the journal of American Academy of Child & Adolescent Psychiatry (Reese Albright, 2012). Thus, showing the importance of investigating alternative methods for the management of ADHD.

This research investigates the possibility of using musical therapy to improve concentration with the goal to assist ADHD individuals in managing the condition. Throughout South Africa, most people own or have access to a pair of headphones, the impact of treating ADHD through your headphones and cell-phone could thus have a significant positive impact on these individuals.

2 Literature review

2.1 Central Nervous System

The body's function is mostly controlled by the central nervous system (CNS), which consists of two parts known as the spinal cord and the brain. The CNS acts as the integrating and command centre of the nervous system. Thus, it interprets incoming sensory information and relays instructions to the peripheral nervous system (PNS), which includes the parts of the nervous system outside of the CNS. This section of the study focusses on the CNS looking at the brain.

2.1.1 The Brain

The brain is a complex organ and is constantly active. It does not matter whether you are asleep, awake or planning your next vacation, your brain is constantly working.

In understanding the brain and its function we need to look at the different regions of the brain as well as their functions. The main organ of the central nervous system is the brain. On average the brain weighs 1.4 kg which is roughly 2% of total body weight (IMotions, 2017). The brain can roughly be divided into four regions known as the brain stem (1), limbic system (2), cerebellum (3) and the cerebrum (4) as seen in Figure 1 below.

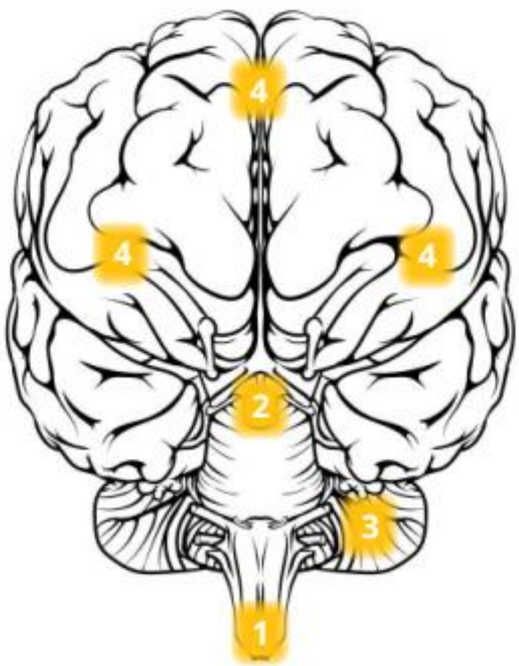


Figure 1: Anterior View of Brain (IMotions, 2017)

The brain stem marked as region one in Figure 1 is the lowest part of the brain comprising of the medulla, midbrain, and pons. The brain stem is known to control autonomic body processes. Autonomic processes include controls such as bladder function, breathing, and heartbeat (Marieb, 2015).

Region two describes the limbic system, which consists of the hypothalamus, amygdala, and amygdala. This region of the brain is known to host the emotional part of the brain that plays a role in fight-or-flight situations. The cerebellum shown in region three is known to regulate and control balance, posture, and movement (Marieb, 2015).The cerebellum receives impulses from the spinal cord and integrates these systems to fine-tune motor activity. The largest part of the brain is the cerebrum or cortex indicated by region four. This region is associated with higher brain function such as action selection, control, and conscious thoughts. The cerebrum consists of two parts or hemispheres known as the left and right hemispheres which are not directly connected (Marieb & Keller, 2018). The cerebral cortex can be roughly divided into four sections known as lobes. The four lobes can be seen in Figure 2 which are the occipital (5), temporal (6), parietal (7) and frontal lobe (8).

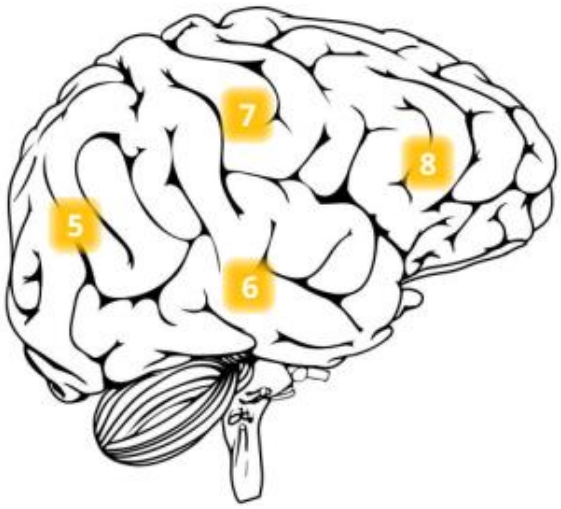


Figure 2: Cerebral Cortex Lobes (IMotions, 2017)

The occipital lobe indicated by region five in Figure 2 is known as the visual processing centre of the brain. The occipital cortex located at the rearmost portion of the skull processes all the things we as humans see (Marieb & Keller, 2018). Region six indicates the temporal lobe, which is responsible for long-term memory as well as language comprehension, production, and processing (Marieb & Keller, 2018).

The parietal lobe is shown in region seven is all about integrating information. The information includes all internal sensory feedback from eyes, head, skeletal muscles, limbs, otoliths, etc (Marieb & Keller, 2018).

Prescription stimulants for ADHD enhance the activity of the primary neurotransmitters known as dopamine and noradrenaline to reduce symptomatology in ADHD (Durston, 2003). Catecholamine transmitters such as dopamine and noradrenaline are known to have a powerful impact on attention and working memory (Xing, Li & Gao, 2016). The medication for ADHD available and approved by the U.S. Food and Drug Administration, enhance catecholamine transmission in the prefrontal cortex (Arnsten & Pliszka, 2011). To understand how neurotransmitters work, there needs to be an understanding of the physiology of neurons or nerve cells.

The following main structures are present in a neuron; the cell body, nucleus, dendrite, dendrite branches, axon and axon terminals, (Marieb, 2015). The function of neurons is to transport electrical signals (messages) from the receptors to the cell body and finally to the axon terminals. The axon terminals of the presynaptic neuron transmit electrical signals to the postsynaptic neuron via a synaptic cleft. The synaptic cleft is a small gap separating the axon terminal from the next neuron (Marieb, 2015).

Signals are transmitted through the synapse in the following order: The action potential arrives at the axon terminals and the electrical change allows the calcium channels to open. The calcium allows small vesicles containing the neurotransmitter to fuse to the axon terminal membrane. This action releases the neurotransmitter molecules to diffuse across the synaptic cleft and bind to the receptor's proteins of the next neuron. The action causes ion channels to open or close, thus, eventually leading to a nerve impulse in the neuron beyond the synapse (Marieb, 2015).

Noradrenaline, better known as the stress hormone, is widely distributed across the cerebral cortex and affects the part of the brain where attention and responding actions are controlled (Fuster, 2008). Noradrenaline is a hormone that normally causes an increase in blood pressure, dilation of pupils, heart rate, increases blood flow to skeletal muscles as well as a dilation of air passages in the lungs (Chung, 2006). The hormone is synthesized from dopamine by dopamine β-hydroxylase and the actions of noradrenaline in the prefrontal cortex are dependent on other neurotransmitters such as dopamine (Fuster, 2008).

Dopaminergic systems are known to originate from the ventral tegmental area, situated next to the substantia nigra in the midbrain located in the brain stem as seen at number one in Figure 1 (Fuster, 2008). The large population of dopamine neurons present in the ventral tegmental area travel to other regions of the brain via several major pathways. The most prominent pathways are the mesostriatal and mesocortical dopamine systems (Fuster, 2008).

The mesostriatal pathways project from the ventral tegmental area to several limbic structures and are most frequently associated with the reward system involving the amygdala and hippocampus, (Pariyadath *et al.*, 2016). On the other hand, the mesocortical pathways project from the ventral tegmental area to widespread areas of the cerebral cortex primarily to the prefrontal cortex (Pariyadath *et al.*, 2016).

The prefrontal cortex is known as the part of the brain located at the front of the frontal lobe indicated by region eight in Figure 2. This region is associated with problem-solving, working memory, language comprehension, behaviour, and judgment (Marieb, 2015). The prefrontal cortex has been the subject of numerous ADHD studies.

Previous studies concluded that the dorsolateral prefrontal cortex indicated smaller volume as well as reduced activity in comparison to individuals unaffected by ADHD (Castellanos *et al*., 2005). A reduction in the volume of the caudate, corpus callosum and cerebellum for ADHD individuals in comparison to unaffected peers was also observed, (Castellanos *et al.*, 2002; Seidman *et al.*, 2005). Rubia *et al.* (2005) found that tasks that require attention were responsible for a decrease in prefrontal cortex activity. According to the aforementioned research, the target region of this project is the prefrontal cortex as this region is known to be impacted by ADHD.

2.2 ADHD

2.2.1 What is ADHD?

Attention-Deficit/Hyperactivity Disorder or commonly known as ADHD is a chronic condition characterized by three primary symptoms: impulsivity, hyperactivity, and difficulty focusing and sustaining attention (Health 24, 2017). Children, as well as adults, can be affected by this condition although this condition has been found to be passed on from relatives to children. The children of a parent who has ADHD has up to 50% chance of being affected by the condition (Barkley, 1998).

The condition usually arises between the ages of three and five-years old. It has been found that boys are at least three times as likely to develop the condition compared to girls (Barkley, 1998). Studies indicate that sex differences in adulthood almost disappear (Faraone *et al*., 2015).

Contrary to popular belief, ADHD cannot be caused by dietary factors, such as the amount of sugar a child consumes or from a certain lifestyle (Barkley, 1998). Therefore, it is important to determine the underlying neural substrate of ADHD and the neurobiological basis. Treating ADHD successfully is important as it has great morbidity associated with it. The effects of ADHD on individuals can include impaired academic, social and occupational functioning (Bush *et al.*, 2008).

The symptoms of ADHD vary and are usually difficult to identify. The symptoms may include self-focused behavior, emotional turmoil, fidgetiness, trouble getting organized, lack of focus and forgetfulness (Healthline, 2017). The diagnosis for ADHD is difficult as symptoms vary from person to person.

Where ADHD is suspected, a specialist will begin to gather information on the patient's behaviour. The physician will look into the nature of the patient's home and school/workplace to find out whether they are usually stressful or chaotic. The data will then allow the specialist to create a profile for the patient and to decide which ADHD symptoms the patient shows.

Psychiatrists will use similar criteria as illustrated in Table 1 (Barkley, 1998). Individuals will normally be diagnosed with the condition if a person displays at least six or more symptoms of hyperactivity and impulsivity or inattention, (Barkley, 1998).

Table 1: Criteria for diagnosing ADHD, adapted from Barkley (1998)

INATTENTION	HYPERACTIVITY AND IMPULSIVITY
Fails to give close attention to details or make careless mistakes in schoolwork or other activities	Fidgets with hands or feet or squirms in seat
Has difficulty sustaining attention in tasks or play activities	Leaves seat in classroom or in other situations in which remaining seated is expected
Does not seem to listen when spoken directly	Runs about or climbs excessively in situations in which it is inappropriate
Does not follow through on instructions and fail to finish schoolwork, chores or duties in the workplace	Has difficulty playing or engaging in leisure activities quietly
Has difficulty organizing tasks and activities	Is "on the go" or acts as if "driven by a motor"
Avoids dislikes or is reluctant to engage in tasks that require sustained mental effort	Talks excessively
Loses things necessary for tasks or activities	Blurts out answers before a question has been completed
Is easily distracted by extraneous stimuli	Has difficulty awaiting turns
Is forgetful in daily activities	Interrupts or intrudes others

The Diagnostic and Statistical Manual of Mental Disorders has well-established criteria for the diagnosis of ADHD (Kennel, Taylor, Lyon & Bourguignon, 2010). In the case of a diagnosis, further tests may include mental health, intelligence and learning achievement (Martin, 2016).

It is estimated that 78% of children with ADHD will continue to display symptoms as teenagers (Kennel *et al.*, 2010). ADHD will persist into adolescence with a decrease in symptoms of hyperactivity, although impulsivity and inattention will often persist (Kennel *et al.*, 2010).

A study by the National Institutes of Health, investigated the risks of children and adolescents to substance use (Marshal *et al*., 2003). The study found that adolescents with ADHD, have a greater chance to become dependant on alcohol, illicit drugs and cigarettes. Compared to unaffected peers, the adolescents were more likely to become dependent on theses substances (Marshal *et al.*, 2003). Depression and poor self-esteem are also common among college students with ADHD (Murphy, Barkley & Bush, 2002). This indicates that ADHD is a serious condition and finding alternative methods for the management of this condition is of significant importance.

The obstacles associated with ADHD among college students suggest that students with ADHD are known to be more likely to fail and/or drop out of school. This could be is due to attentional problems, irregular study habits, poor organizational skills and, the inability to have appropriate social skills (Murphy *et al.*, 2002).

The effects of ADHD become more worrying as 30% of people diagnosed with ADHD are known to not respond to stimulant medication. Individuals usually experience unpleasant side effects that may include irritability, nausea, headaches, and insomnia (Kennel *et al.*, 2010). Although there is no cure for ADHD, finding an adjunct therapy method for the management of this disorder that is inexpensive will allow individuals in third-world countries the possibility of managing ADHD.

2.2.2 ADHD and the Brain

ADHD can be classified as a brain disorder and is caused by differences in neurotransmitter patterns in certain areas of the brain as explained in Section 2.1 (Sinfield, 2018). Dopamine is closely related to the reward centre of the brain and reacts with other neurotransmitters to regulate mood. In the case of low dopamine levels, the individual is usually driven to seek rewards by other means.

Dopamine is secreted by the neurons in certain parts of the brain to modulate or inhibit the activity of other neurons, particularly those involved in movement and emotion (Barkley, 1998). The movement of Parkinson's disorder is caused by the decrease of dopamine secreting neurons in the region of the brain called the substantia nigra (Meder *et al*., 2019).

The National Institute of Mental Health found that the two basal ganglia regions called the caudate nucleus and the globus pallidus as well as the right prefrontal cortex are significantly smaller in children with ADHD compared to those without (Barkley, 1998). In Figure 3 is a picture of a normal brain indicating the regions of the brain reduced in size.

One of the largest sample studies conducted to date was done by Hoogman *et al.* (2017) and involved more than 3 242 people between the ages of four and 63. The study investigated structural differences using MRI data from ADHD individuals as well as individuals without a diagnosis (Hoogman, *et al.*, 2017).

In the study, 1 713 individuals were diagnosed with ADHD. The six regions found to be impacted by ADHD had a significantly smaller volume compared to unaffected individuals. The regions are the accumbens, amygdala, caudate, hippocampus, putamen and intracranial volume (Hoogman *et al.*, 2017).

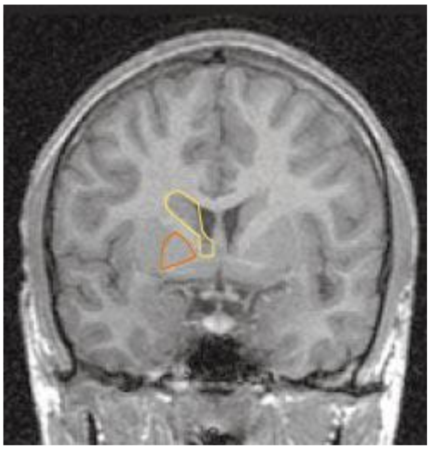


Figure 3: Image outlines the Globus pallidus (red) and the right caudate nucleus (yellow), (Barkley, 1998)

The largest differences in volume were observed in the amygdala. The region is known to play a key role in regulating emotions, therefore, ADHD can be closely related to emotional regulation problems (Hoogman *et al.*, 2017). The study also found that the differences in brain volume observed are more prominent in the brains of children with ADHD than with adults with the same disorder (Hoogman *et al.*, 2017). Consequently, the study strongly suggests that ADHD is related to the brain and not "just a label" for difficult children.

Faraone *et al*. (2005) completed a study that also investigated the effect of ADHD on the brain. The study looked at the maturation of the cerebral cortex and found that ADHD is associated with delayed maturation of the cortex. It has been found that the age for reaching peak cortical thickness was 10.5 years for patients with ADHD and a mere 7.5 years for unaffected peers (Faraone *et al*., 2015). The study found the delays to be more prominent in the prefrontal region of the brain; the region which is of interest to this study.

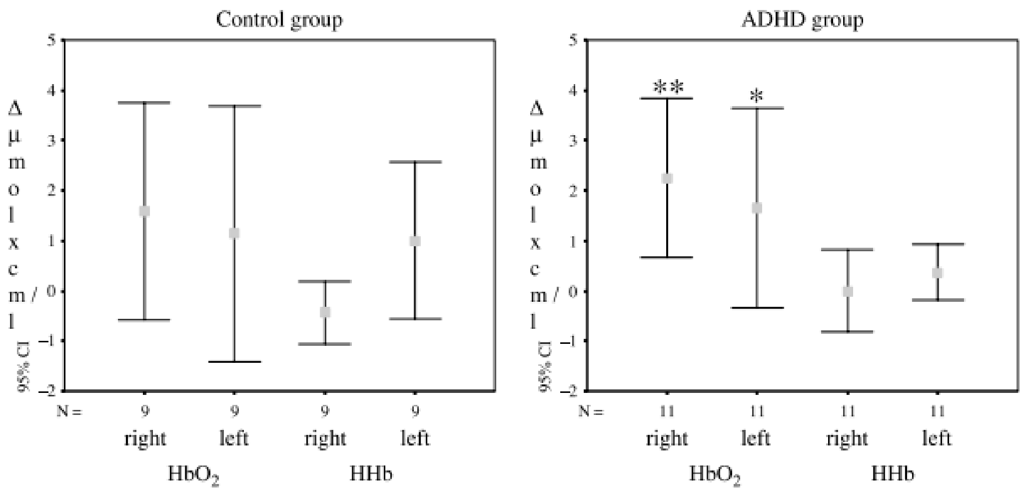
The above-mentioned studies made use of MRI data. In contrast, Moser *et al.* (2009) investigated how the Stroop test activates the right prefrontal cortex in ADHD individuals using a functional near-infrared spectroscopy device. In the study, 12 healthy boys were compared to 12 medication-free boys with ADHD. A repeated-measures analysis of variance (ANOVA) was conducted comparing reaction time for the Stroop task against controls.

The study found that the mean reaction time was significantly longer ($p = 0.002$) for individuals with ADHD. fNIRS results indicated that there were no significant changes between the two mean concentration levels (oxy-haemoglobin and deoxy-haemoglobin) among the two groups in the dorsolateral region, (Moser *et al.*, 2009).

An attention task with fNIRS was used in another study by Weber *et al.* (2005) to investigate the cerebral hemodynamic changes in the prefrontal cortex for boys with ADHD as well as an unaffected control group. Children were instructed to complete a trail-making test as this procedure served as a measurement for executive functions. This test required participants to connect numbers from one to 90 in ascending order using paper and pencil. Before each test the boys completed a baseline recording looking at a picture book without any task.

The study calculated the mean concentration of oxy- and deoxy-haemoglobin for the whole durations of a trial-making test. Individuals with ADHD showed a significant increase in oxy-haemoglobin on the right side of the prefrontal cortex while deoxy-haemoglobin did not indicate any changes compared to baseline. The control group did not indicate any significant difference between the left and right side of the PFC compared to baseline (Weber *et al*., 2005).

The results can be seen below in Figure 4. No significant difference was indicated during the control group for oxy- and deoxy-haemoglobin compared to the baseline. However, a significant difference of activation was observed when comparing oxy-haemoglobin of the left side of the PFC to the right side of the PFC to the baseline recording. No difference was observed for deoxy-haemoglobin (Weber *et al.*, 2005). Thus, indicating that oxy-haemoglobin was responsible for inducing the greatest activity.



Mean (± standard deviation) changes of oxy-haemoglobin (HbO2) and deoxy-haemoglobin (HHb) during the attention task. (*p < 0.05, **p < 0.01)

Figure 4: Control vs ADHD (Weber *et al.*, 2005)

Given that the prefrontal cortex appears to be one of the primary areas affected by ADHD, this project focused on the prefrontal cortex.

2.2.3 Treating ADHD

The criteria for diagnosing ADHD were previously stated in Table 1. It is worth noting that clinicians have a huge task of whether a diagnosis of ADHD is appropriate. ADHD symptoms can be subtle and resemble other illnesses, thereby increasing the difficulty of diagnoses. Different cultural and ethnic differences can hinder diagnoses as well as the willingness of patients to report symptoms and acceptance of diagnoses.

A study found that African-American youths had more ADHD symptoms than Caucasian youths but were only diagnosed two-thirds as often (Faraone *et al.*, 2015). As this condition is normally diagnosed as a child, adults remain the source of communication for the child. ADHD has a significant negative impact on different aspects of life such as self-esteem, social functioning, and academic functioning (Kwon, Kim & Kwak, 2018).

University students have been found to be more dependent on alcohol and illicit drugs compared to unaffected peers (Upadhyaya, *et al.*, 2005). In adulthood, some patients will try their best to accommodate the symptoms. Once diagnosed there are two possibilities of treating the condition: pharmacological and non-pharmacological approaches.

The pharmacological approach normally involves choosing a stimulant medication, the first decision is whether to choose a methylphenidate or amphetamine product. The drugs increase the levels of dopamine and norepinephrine as explained in section 2.1. Both of the families of stimulants have short-acting (2-4 hours), intermediate-acting (6-8 hours) and long-acting (10-12 hours) formulations. Popular stimulants used to treat ADHD include Concerta, Adderall, and Ritalin (Cleveland Clinic, 2019).

It has been found that approximately 70% of children with ADHD show improvements in behavioural, social skills, attention, and cognitive functions in response to methylphenidate (Dolu *et al.*, 2019).

Common side effects of ADHD medication may include sleep problems, decreased appetite, dizziness, dysphoria, increased blood pressure and irritability (Faraone *et al.*, 2015). A study conducted by Dolu *et al.* (2019) investigated the effects of methylphenidate treatment in children with ADHD by taking a functional near-infrared approach (fNIRS). They found that the right prefrontal cortex was responsible for greater activity in individuals with ADHD compared to unaffected peers. The study also determined that the right prefrontal activation was normalized after three months of methylphenidate therapy. Therefore, the methylphenidate was found to correct prefrontal activation.

This study aims to investigate a non-pharmacological approach A non-pharmacological approach should be considered in the following instances: some patients do not respond positively to the medication and might experience unmanageable adverse effects, medication alone might not produce optimal results, and lastly patients might not have access to medication due to parents or clinician concerns or restricted government policies that limit access (Faraone *et al.*, 2015).

The non-pharmacological approach includes a few therapy methods such as music therapy, behavioural therapy, child and parent training, psychological education as well as exercise and diet.

Behaviour parent training has been found to be effective in reducing ADHD symptoms (Ciesielski *et al*., 2019). Changing meal plans to increase certain nutrients such as iron, zinc, fatty acids and protein can help brain functioning, (Williams, 2019). Artificial food colouring, as well as preservatives, must be avoided (Stevens *et al.*, 2010). It is important to note that different foods may have different effects on people, therefore, Stevens *et al.* (2010) suggest that if no effects can be seen within two weeks the individual should change diet. Exercise can improve general health and lead to improvement of focus and attention. However, no research has been done on the effects of exercise on ADHD.

Brain-training such as neurofeedback is also becoming popular as an alternative solution to increase working memory and attention by using computer-based exercises. Real-time displays of brain activity are used in an attempt to teach the patient to self-regulate brain function. Different neurofeedback training exists using either near-infrared spectroscopy (NIRS), EEG or MRI is currently used.

A pilot study conducted among children aged seven to 10-years old investigated NIRS as a neurofeedback treatment method for ADHD. Oxy-haemoglobin was observed in the prefrontal cortex where after parents and teachers rated ADHD symptoms. The study concluded that ADHD symptoms decreased significantly after four weeks as well as six months after training. The study came to the conclusion that NIRS-neurofeedback seems to be a feasible ADHD management method (Marx *et al.*, 2015).

The goal of EEG- brain training is to teach individuals to increase attentiveness and reduce impulsivity by teaching individuals to predisposition their brains to beta wave patterns (Lofthouse *et al*., 2011). The wave patterns associated with the brain are explained in Section 2.3 under electroencephalography. The same study by Marx *et al.* (2015) investigated how EEG-neurofeedback compares to NIRS-neurofeedback and found that NIRS is a more time-effective method.

Neurofeedback training that uses EEG has been found to be an efficacious treatment method (Lubar *et al*., 1995). Neurofeedback effects on ADHD individuals can be seen as “probably efficacious” as research has mixed feelings of this topic (Lofthouse *et al.*, 2011).

Sound therapy is becoming a popular alternative as music and auditory stimuli are becoming popular among young people. In this chapter, Section 2.5 investigates the effect of background music on individuals.

The first step is to understand how sound is interpreted by the body as this study investigates the effect of music on the brain. In short, the ear is anatomically divided into three major areas known as the external, or outer, ear; the middle ear, and the internal ear structure or inner ear (Marieb & Keller, 2018). The ear is illustrated in Figure 5.

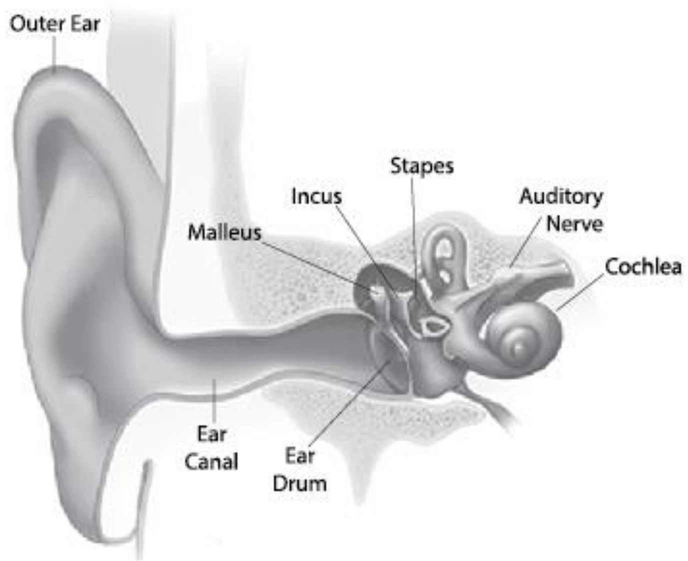


Figure 5: The Ear (NIH, 2015)

Sound waves travel through the outer ear reaching a narrow passageway known as the ear canal (NIH, 2015). The eardrum starts to vibrate the moment the sound waves reach the end of the ear canal. The vibrations initiate movement of the three ear bones known as the malleus, incus, and stapes (NIH, 2015). The bones situated in the middle ear have the function of amplifying the vibrations sending the vibrations to the cochlea.

The cochlea is a snail-shaped structure filled with fluid. The vibrations cause the fluid inside the cochlea to ripple and stimulate hair cells on the membrane of the cochlea (NIH, 2015). Hair-like structures known as stereocilia located on top of the hair cells, are grouped together inside the cochlea as bundles. The hair cells in the cochlea ride the sound waves and the hair bundles are moved.

The movement of the hair bundle located on top of the cells turns these movements into electrical signals by chemicals rushing into the cells (NIH, 2015). The auditory nerve carries the electrical signals to the brain, which turns it into sounds we recognize.

When we hear sounds the two hemispheres (right and left) work together in the brain to process the tune and analyse the structural components of the music, while on the other hand, the limbic system activates an emotional response in the listener (Schwartz, Ayres & Douglas, 2017).

As with all treatment methods, the advantages and disadvantages have to be weighed against one another to determine the correct managing method of ADHD. The following factors need to be considered benefits, cost, accessibility, and potential harm.

2.3 Brain Activity Monitoring

Different neuroimaging techniques exist. In this section, the three different techniques are investigated.

2.3.1 Electroencephalography (EEG)

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity in the brain, using electrodes placed on the scalp. In the beginning, it was noted that electrical activity was present when individuals performed tasks that require attention (Woodman, 2010). Scientists began to investigate and take advantage of signal averaging. As a result, the Event-Related Potentials (ERP) technique became the primary tool for investigating cognitive neuroscience (Woodman, 2010).

ERP is a specific brain response that can be directly related to a specific cognitive, motor or sensory event. Attention and perception appear to operate on a scale of tens of milliseconds, thus, the ERP technique is an ideal solution to measure brain activity as it has a good temporal resolution (Woodman, 2010). EEG devices are one of the most familiar devices to use in brain monitoring as they are relatively cheap, non-invasive, safe to use and have an excellent time resolution.

However, ERP has a large drawback, which is the inability to resolve the activity of individual neurons (Woodman, 2010). For an electrical field to be large enough to propagate through the brain, dura, skull, and skin a large number of neurons need to fire simultaneously (Woodman, 2010). The other drawback is that the group of neurons that fire simultaneously need to be perpendicular - relative to the surface of the skull – to ensure that other neuronal ensembles that are active at the same time with opposite direction, will not cancel out the activity (Woodman, 2010).

EEG signals are always a mixture of several underlying base frequencies, which reflect certain attentional or cognitive state (Britton *et al.*, 2016). The frequencies' bands were classified according to 5 ranges: Delta band (0-4 Hz), the theta (4-7 Hz), the alpha band (8-12 Hz), the beta band (13-25 Hz) and gamma band (>25 Hz), (Britton, Frey & Hopp, 2016b). Delta waves are characterized as deep sleep, which is typically localized in the thalamus (Britton *et al.*, 2016b).

Theta waves have been reported to be associated with the difficulty of mental operations such as during focused attention and information uptake. Theta waves become more prominent in increasing task difficulty (Britton *et al.*, 2016b). Theta waves could be considered as a solution for concentration monitoring due to previous studies, which suggest working memory or mental workload is related to this kind of wave pattern (Awang *et al.*, 2011).

On the other hand, alpha waves correlate to reflecting sensory, motor and memory functions (Britton *et al.*, 2016b). The brain has shown an increase in alpha waves during mental and physical relaxation with eyes closed (Britton *et al.*, 2016b). The beta band frequencies are both generated in posterior and frontal regions. Beta frequencies are known to be associated with active, busy or anxious thinking.

Active concentrating is known to correlate with higher beta power (Britton *et al.*, 2016b). Gamma bands, on the other hand, are described as the 'black hole' of EEG research (Britton *et al.*, 2016b). The locations at which gamma frequencies are generated as well as what the oscillations, reflect are still unknown.

It is clear from the above that EEG analysis is a useful tool in analyzing brain waves to determine certain underlying functions of the brain.

2.3.2 Magnetic Resonance Imaging

Magnetic Resonance Imaging or better known as MRI is a non-invasive test that produces detailed images of the brain. Images are created by using a magnetic field and radio waves (HealthLine, 2017). MRI scans are different from X-ray and CT scans as they do not make use of radiation to produce images.

MRI scans look at anatomical structures of the brain by creating high-resolution images that show contrast between different tissues. MRI scans are useful for detecting structural changes in the brain such as tumours.

On the other hand, functional magnetic resonance imaging (fMRI) has to do with mapping brain activity by providing the Blood-oxygenation level dependent (BOLD) contrast. fMRI focuses on brain activity by looking at blood flow, specifically oxy-haemoglobin (Devlin, 2018).

The advantages of MRI and fMRI include; the imaging method is safe, non-invasive and images produced from MRI are of high resolution for viewing soft tissue structures. The disadvantages of this method include: a high sensitivity to motion artefacts, MRI is expensive and the device is not portable.

fMRI data have lower temporal resolution compared to EEG (Devlin, 2018). Although MRI and fMRI scans are useful brain imaging methods, the current study is looking for an imaging method that is portable, easy to use, easily accessible and less costly.

2.3.3 Near-infrared Spectroscopy (fNIRS)

Near-infrared spectroscopy (fNIRS) is a non-invasive method of detecting brain activity by monitoring changes in blood oxygenation levels. This method measures the absorption of near-infrared light between 650 nm and 950 nm through the skull (Ye *et al.*, 2008). The absorption spectra of deoxy-haemoglobin (HbR), oxy-haemoglobin (HbO) are distinct in the brain.

In the fNIRS method, a laser is used to project a near-infrared light beam into the scalp as well as a detector that detects light returning to the surface of the head after multiple scattering. The method of the laser and detector placement is illustrated in Figure 6 below.

In the brain, the photons are absorbed primarily by deoxygenated and oxygenated haemoglobin (HbR and HbO) (Naseer & Hong, 2015). Suitable photon detectors record the returning photons. The changes recorded can be used to calculate the concentrations of HbR and HbO by using the modified Beer-Lambert law (MBLL).

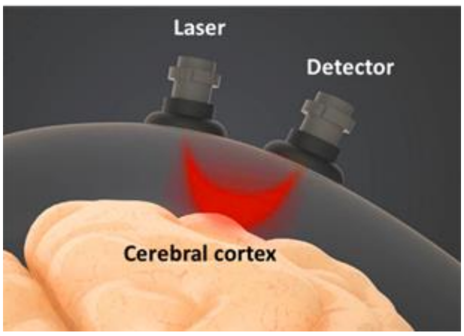


Figure 6: Laser and Detector (Obelab, 2018)

The exact proportions of light that are scattered or absorbed depends on the properties of the medium. In ideal cases, most of the light is absorbed or transmitted and the Beer-Lambert law can be described (Gervain *et al.*, 2011):

$$A = -\log\left(\frac{l}{l_0}\right) = c \times \varepsilon_\lambda \times l \qquad (1)$$

A is described as the absorbance, l is the incident light intensity, l_0 is the detected light intensity, c is the density or concentration of the medium, ε_λ is the molar extinction coefficient characteristic of the medium for a light of wavelength λ, and l is the distance that the light travels through the medium with the relevant dimension (Gervain *et al.*, 2011).

Knowing the original light intensity, molar extinction coefficient and distance to the medium, the above equation can be used to calculate the relevant concentrations of the medium by measuring the intensity of light that. The above relationship can be used to calculate these concentrations.

Concentrations can be calculated by shining light of a certain wavelength on the head and measuring the intensity of the exiting light. However, biological tissue like the skin, brain and skull are highly scattering media so the equation needs to be modified. The modified equation takes into account that light does not travel through the medium in a straight line. The modified Beer-Lambert law states the following (Gervain *et al.*, 2011):

$$-\log\left(\frac{l}{l_0}\right) = (c \times \varepsilon_\lambda \times l \times DPF) + G \qquad (2)$$

DPF or differential pathlength factor accounts for the non-linear trajectory of the light in biological media and G is the scatter. Using continuous wave (CW) techniques these factors cannot be measured directly. Therefore, the absolute values for deoxy-haemoglobin and oxy-haemoglobin cannot be obtained. The scatter is however constant and therefore can be eliminated when changes in concentrations of deoxy-haemoglobin and oxy-haemoglobin are calculated:

$$\Delta A = (\left(\Delta c_{oxy} \times \varepsilon_{\lambda_{oxy}}\right) + \left(\Delta c_{deoxy} \times \varepsilon_{\lambda_{deoxy}}\right)) \times l \times DPF \qquad (3)$$

When two wavelengths are used, yielding two equations, the relative concentrations of deoxy-haemoglobin and oxy-haemoglobin ($\Delta c_{deoxy}, \Delta c_{oxy}$) can be calculated from the change of absorbance (ΔA).

The main advantages of using fNIRS include its affordability as well as portability. The fNIRS system also has a high degree of flexibility as the device is a compact measuring system compared to fMRI.

fNIRS is also completely silent compared to fMRI, creating a silent environment for when participant needs to be exposed to auditory stimuli. No radio frequency pulses are involved and there are no strong magnetic fields. The system has the advantage of measuring both oxy-haemoglobin and deoxy-haemoglobin as well as total-haemoglobin. fNIRS systems are also less sensitive to motion artefacts compared to both EEG and MRI, (Gervain *et al.*, 2011).

However, the disadvantages include poor spatial resolution as well as limited penetration depth due to high levels of light scattering within the tissue. Signals may often be corrupted by measurement noise of physiological-based systemic interference. fNIRS can also not penetrate through hair as darker colour hair absorbs light. One of the key limitations of the system is that it only probes the surface layers of the cerebral cortex. Brain structures that lie deeper in or below the cerebral cortex are not visible through this technique. This leads to a diverse set of brain areas that cannot be detected such as the thalamus, hypothalamus, pituitary glands and hippocampus.

The spatial resolution of fNIRS is inferior to that of MRI as well as the time resolution to that of EEG (Gervain *et al.*, 2011). The temporal resolution of fNIRS can be compared to MRI. As with any neuroimaging tool, the advantages and disadvantages have to be weighed against one another to determine the ideal neuroimaging tool for this experiment.

2.4 Music and the Brain

It does not matter if it’s, Justin Bieber, Bruno Mars or Frank Sinatra - your favorite music most likely triggers a similar type of activity in your brain as other people's favorites do in theirs.

Music activates many regions of the brain at once. The frontal region, temporal region, parietal, and subcortical regions are known to be affected (Weeks, 2011). These areas of the brain are responsible for working memory, sematic processes, attention, emotions, and syntactic process. It is known that the most influential type of music lies solely in the way it is composed. Psychological studies show that listeners are consistent in associating basic or primary emotions such as sadness, happiness, anger, and fear to musical compositions (Schmidt & Trainor, 2001).

Studies indicate that most work has been done on Western-style compositions, and the well-structured music of Mozart and Bach has been a popular choice for music therapy (Trimble & Hesdorffer, 2017).

Dr. Burdette (2017), concluded that researchers found that listening to favorite songs altered the connectivity between the auditory brain areas and a region responsible for social emotion consolidation and memory.

In another study it was found that music training from a young age correlates with plastic changes in the motor, auditory and sensorimotor integration areas (Miendlarzewska, EA Trost, 2014). It is clear that music has an effect on the brain, however, what is still unknown is what effect do other factors such as family background, motivation, the genre of music, etc have to do with brain development?

Musical training of children is known to increase listening skills, including sound discrimination, an ability also involved in speech segmentation (Miendlarzewska, EA Trost, 2014). It is theorized that listening to music helps people overcome stress due to cognitive dissonance that is necessary for accumulating knowledge, (Cabanac *et al*., 2013). This could be the reason why students listen to music as a method to help manage stressful situations. It is clear that music has a profound effect on the brain, although, what is still unclear is if music has a profound effect on an ADHD brain.

2.5 Music and Cognitive Performance

Today, it is unusual for people to not be around music as the availability of portable devices as well as free music on the internet increases. Anderson and Fuller (2010) found that about 70% of students listen to music while studying. Different musical genres may have different effects on people. The goal of a study conducted by Schellenberg *et al.* (2007) was to examine the specific type of musical experience that will lead to enhanced cognitive performance.

The study conducted an experiment with Japanese children under the age of five years. 13 Boys and 26 girls from two kindergarten classes were asked to make a drawing whereby the creativity of the children will be rated (Schellenberg *et al*., 2007). The drawings of the children were rated by 18 female undergraduates on three different scales known as creativity, energy and technical proficiency. The drawings of the children were rated before listening to music as well as after listening to music. The class of children was randomly divided into four groups whereby each group was either exposed to Mozart or Albinoni or familiar children's songs and another group sang familiar songs. The children's songs had Japanese lyrics but they were all in Western major keys (Schellenberg *et al*., 2007).

Initially, each child made a baseline drawing whereby the drawings were examined after stimulation. The results concluded that drawing times increased reliably from the baseline after listening to familiar music (Schellenberg *et al*., 2007). The drawing times did not increase for children who heard Albinoni or Mozart. The average increase of drawing times by the experiment can be seen in Figure 7 below. An increase in drawing time was seen as positive, as it is related to more creativity.

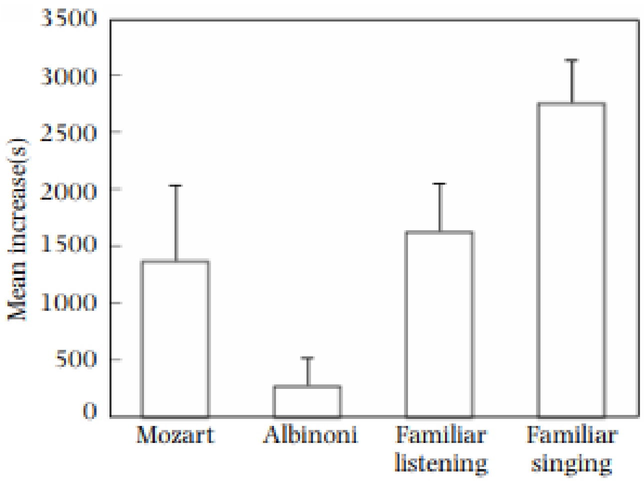


Figure 7: Mean Increase in Drawing Times (Schellenberg, E. Glenn; Nakata, Takayuki ; Hunter, Patrick G; Tamoto, 2007)

Similarly, children who heard familiar songs created drawings post-music which were more creative, energetic, and technically proficient (Schellenberg *et al*., 2007). The average creativity, energy and technical proficiency ratings made by adults of the children's drawings can be seen in Figure 8.

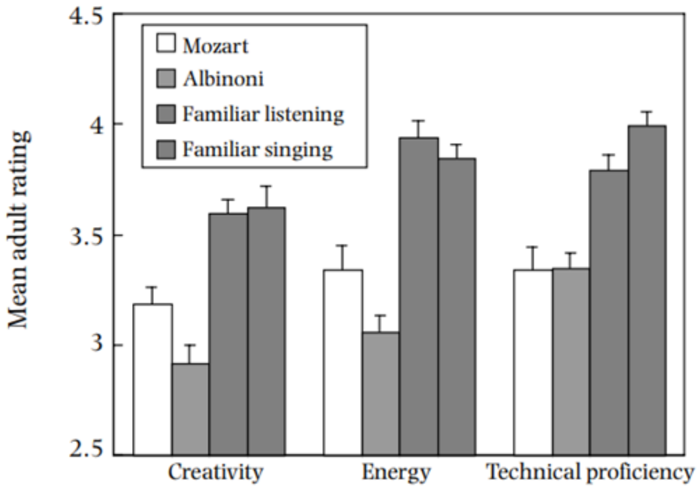


Figure 8: Mean Ratings made by Adults (Schellenberg, E. Glenn; Nakata, Takayuki ; Hunter, Patrick G; Tamoto, 2007)

The results from this study came to the conclusion that participants who differ in age and cultural background will have different responses to certain genres of music (Schellenberg *et al*., 2007). The study proved that familiar types of music known by the children had a more prominent effect on cognitive performance. Although, this study is an early indication of the effects of different music experiences on cognition it deserves further investigation.

The effect of music was also investigated to determine whether music enhances cognitive recovery and mood after a middle cerebral artery stroke (Särkämö *et al*., 2008). The study found that the recovery of verbal memory and focused attention improved significantly more than in control groups. The music group also experienced a less depressed and confused mood versus control groups. This study is another example of the positive effect that music therapy can have.

The fundamental problem that still needs to be solved is whether it is possible to generalize a genre of music that could have the same cognitive effect on everyone?

In another study, the researchers investigated whether background music has an effect on the concentration of workers. Music is everywhere from hospitals, shops or even offices. In the study, numerous psychologists studied the possible effects of music on human behavior (Huang & Shih, 2011). With regard to the rhythm of background music, the individuals demonstrated to pick up the pace involved in the exercise to match that of the music. Myska and Lindbaek (2000) found that music directly influences both the parasympathetic and sympathetic nervous systems resulting in behavioural and emotional changes.

This is why music in a gym is normally music with a fast rhythm as we as humans would like to keep up with the rhythm/pace. Music with lyrics was found to be distracting while instrumental music improved reading comprehension (Huang & Shih, 2011).

In conclusion, the study of Huang & Shih (2011) showed that comparing situations with background music with no background music, resulted in attention test score increases with the listeners' familiarity and preference towards the background music. The study thus indicates that individual feelings regarding music definitely has an effect on the listener.

The influence of listeners' feelings towards background music was also investigated by Fox and Embrey (1972). In the study, they conducted an experiment to determine whether background music can improve productivity when workers are subjected to repetitive work.

The experiment was conducted in a laboratory where six individuals examined small metal parts on a conveyor belt for 30 minutes (Fox & Embrey, 1972). One in a hundred of the parts was defective meaning it was physically damaged and could not pass over a metal cylinder with an appropriate diameter (Fox & Embrey, 1972). In this experiment, the individuals did their job under four different conditions. The conditions were: with no music, randomly selected music played during the 15th-20th minute of the test section, commercially prepared lively music played during the 15th-20th minute as well as music selected by the individuals played during the 15th-20th minute (Fox & Embrey, 1972). The plots of the fault detection can be seen in Figure 9 below.

In the figure, the plot clearly indicates an improvement in the performance of the task when music was played for a short period to act as a stimulant (Fox & Embrey, 1972). The full line was by taking no music as a base 100 and the broken line represents the percentage decrement in detections during the second 15 minutes compared to the first 15 minutes.

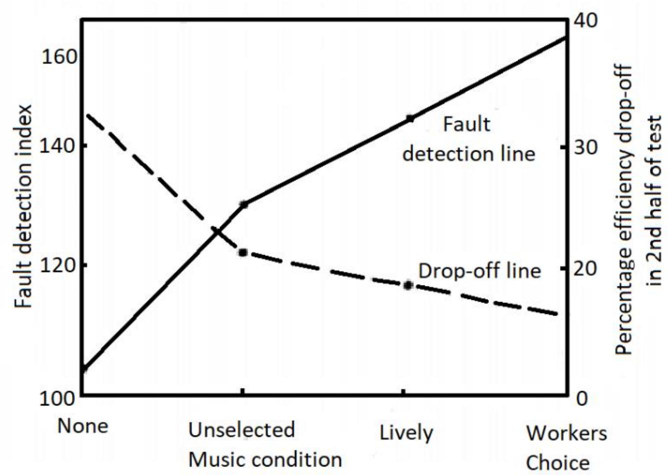


Figure 9: Mean number of detections in individuals, adapted from Fox and Embrey (1972)

The experiment concluded that music of preference (workers' choice) can be used as an aid for productivity (Fox & Embrey, 1972). Studies indicate that background music eases the level of distraction and restlessness keeping the individual focused on the activity at hand (Shih, Huang & Chiang, 2008).

Therefore, supporting the theory that background music can increase productivity/concentration another study introduced background music into a job-training group for chronic psychotic patients. The study found that background music can help individuals to reduce anxiety, complete job assignments more quickly and to increase focus (Huang & Shih, 2011).

In contrast, a study conducted by Ming Chou (2010) explored whether background music has a distracting effect during a reading comprehension task. The study indicated that the type of music played in the background influenced the performance of a cognitive task, (Ming Chou, 2010).

In the end, the study came to the conclusion that the best way for students to study is in a quiet room. Supporting the conclusion of this study another study conducted by Dolegui (2013) came to the same conclusion that students should not listen to any auditory stimuli in order to maintain maximum performance level. Other studies have also found that background music has no effect on memory and may even worsen memory (Hallam *et al*., 2002; Iwanaga & Ito, 2002).

Another study testing the effects of playing music while studying, also found that popular music contained verbal lyrics, potentially caused the most distraction for participants during reading (Dodge & Mensink, 2014). Contradicting the findings of the mentioned studies there exists something called the “Mozart effect”. The “effect” caused widespread attention when an article was published in Nature suggesting that listening to Mozart reported superior spatial ability (Rauscher *et al*., 1993). In this study, adults listened to a 10-minute Mozart piano piece followed by a spatial reasoning test. The study found that adults did significantly better in these tests compared to adults that did not listen to Mozart (Rauscher *et al.*, 1993). It became popularly understood that listening to Mozart could make you smarter.

Music is used as an aid for studying for some individuals whereby other individuals indicate that it has a negative effect. A possible reason why certain individuals can listen to music while studying is related to working memory capacity. A study suggests that the higher an individual’s working memory capacity the better the individual will study with background music (Lehmann & Seufert, 2017). Thus, if an individual's memory capacity is high enough the individual will have sufficient capacity to invest in learning tasks after processing the auditive information.

The use of music for learning also depends on the study material. Highly complex tasks place a burden on working memory capacity compared to content which is less complex. This indicated that background music should only be considered when those tasks are not demanding.

In summary, this section found that music under young Japanese schoolchildren was responsible for creating more creative, energetic and technical proficient drawings. Productivity during fault detection for workers in a lab was also improved by music. Music was also found to be directly related to the parasympathetic and sympathetic nervous systems.

The results from the literature are mixed and some studies indicate that listening to music can improve cognitive ability while some indicate the opposite. This study aims to investigate cognitive ability while listening to different variations of music to determine the impact of music on cognitive ability. The study aims to shed some light on the topic of music as an aid for concentration.

2.6 Cocktail Party Effect

Most people have experienced the cocktail party effect in some form. This phenomenon is known as the ability to focus your auditory attention on a particular stimulus while filtering out a range of other stimuli. As the name suggests this is the effect of speaking to someone in a noisy environment and focusing your attention on the conversation within the noisy environment.

People can shift their attention by focusing on the things that are regarded as important. Studying while listening to music of preference is known to affect the concentration of one person positively, while other people indicate that they get distracted (Dodge & Mensink, 2014; Rauscher *et al.*, 1993). The cocktail party effects can explain the phenomenon behind why some people like to study with music and others not.

Music of preference can be so enjoyable that a person's attention is shifted from the concentration task to rather listening to the music. Factors such as task difficulty, task similarity and practice will affect how we divide our attention. It is important to note that the ability of a person to concentrate depends on the amount of attention a person devotes to the task at hand.

Today everyone has more access to technology than a few years ago. A study done in the United States investigated how media negatively affects academic performance of students (Azam, 2006). Media is known to be a source of distraction for students. Televisions in student rooms are a major distraction as students are more likely to watch television rather than work. According to Azzam (2006), 68% of students have a television in their room exposed to an average of six and a half to eight and a half hours of media a day.

The study also reported that nearly one-third of the students indicated that they talk on the phone, listen to radio or music, instant message, or browse the web while doing homework (Azzam, 2006). Technology is becoming more of a distraction, thus, people need to adapt and control how their attention is divided.

The limited capacity theory suggests that people have a limited amount of information-processing capacity or attention. Information processing is becoming a rare ability as different cognitive tasks compete for the same resources (Ming Chou, 2010). It is believed that with the correct kind of music people can be less stressed, more relaxed, happier and more productive.

3 Methodology

The study aims to investigate the effect of ADHD medication as well as three different musical genres on the performance of a concentration-intensive task for ADHD individuals. In this chapter, the following are discussed: experimental layout, participants recruited, neuroimaging device, music selection, behavioural task selection, experimental setup as well as data analysis.

3.1 Experimental Layout and Design

In order to determine the effects of music and ADHD medication on the prefrontal cortex as well as behavioural data, ADHD individuals were chosen to participate. The musical experience selected for this experiment is classical music, music of participants preference as well as binaural beats. The reason why these different musical experiences were selected as well as different behavioural tasks are explained in this chapter.

The testing period for each participant was across four consecutive days, thus a within-subject experimental design. Consecutive days were chosen in order to keep a person’s state of mind more or less similar as well as excluding any external factors that may have an influence on that day. All testing took place in the morning to allow participants to use medication as they normally do. Each testing period is on a separate day in order to prevent previous testing conditions affecting the next testing period. In order to maintain consistency between tests, each testing slot for every participant was at the same timeslot every day for the whole duration of testing.

The neuroimaging technique chosen for this experiment was a functional near-infrared spectroscopy (fNIRS) device called NIRSIT. The device, as well as the technology, is explained in this chapter. NIRSIT was used to continuously record brain activity during the duration of each test.

Subjects were tested one at a time for a duration of an hour divided into two 30-minute sessions (known as control and treatment test), with a 15-minute break in between for three days. The reason why a break was introduced in the study was to reduce the strain and discomfort on an individual.

The remaining day the participants were also be tested for two 30-minute sessions but with an hour break in between and this is known as the medicated test. The reason why an hour was selected was for participants to take their prescribed ADHD medication and for its effects to take effect. Stimulant medication is effective as soon as they cross the blood-brain barrier, which takes about 45 to 60 minutes (Dodson, 2019).

The general layout for the experiment can be seen in Figure 10. All the days were randomized for each participant meaning that each participant did a different treatment test each day. The four treatment tests are classical music, music of preference, binaural beats as well as ADHD medication.

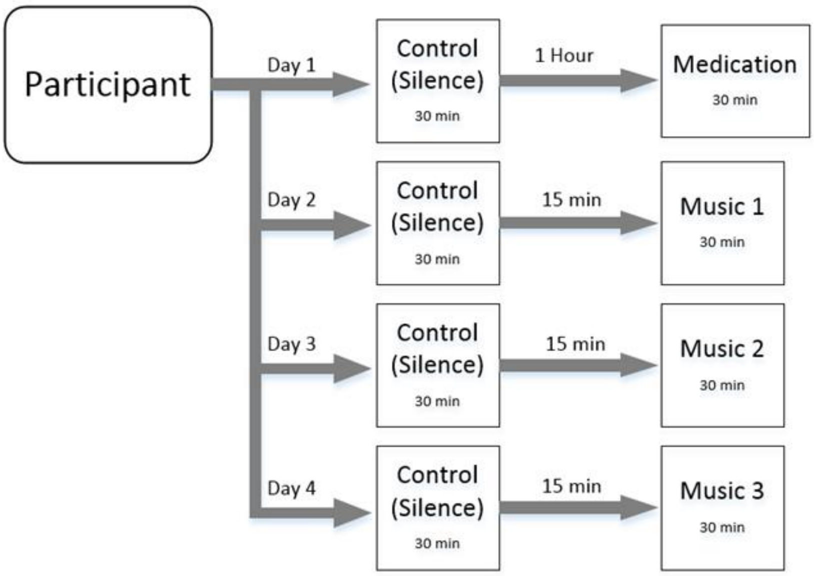


Figure 10: Experimental Layout

In order to present participants with a cognitive challenge to determine how well individuals perform under different treatment conditions, different cognitive tests were selected (Stroop test, Sternberg working memory test, sustained attention test as well as a time perception test).

During each control and treatment period, the four cognitive tests were presented to participants in random order from the 15th minute. Presenting the cognitive tests from the 15th minute was chosen to allow the participants time to listen to the selected musical genre and to experience the auditory stimuli.

Institutional ethical clearance was obtained before the study. A research protocol was submitted to the Human Research Ethics Committee (HREC) of Stellenbosch University where upon project approval was given (S19/04/069). Participants gave informed consent prior to the experiment and the consent document (as seen in Appendix A). The experiment took place at the Department of Mechanical and Mechatronic Engineering in the Engineering Faculty of Stellenbosch University.

No monetary compensation was given to participants although refreshments were provided during the tests.

3.2 Participants

Students at Stellenbosch University between the age of 18 – 25 years who are diagnosed with ADHD/ADD and actively use medication that contains methylphenidate were recruited for this research. A power of 0.9 and an α of 0.05 were established, therefore, a minimum of 13 participants was required.

Thirteen healthy volunteers (9 female and 4 male) with a mean age of 21.85 years and a standard deviation of 2.08 years from the University of Stellenbosch participated in the experiment. All the participants were asked whether they listen to music when studying, 77% of students indicated that they do.

Individuals using immediate-release Ritalin or any short-acting medication that contains methylphenidate were excluded from the study. A long-acting drug such as Concerta increases dopamine steadily, while short-acting Ritalin releases more quickly and this creates hills and valleys in your blood level which is not ideal for this study. Participants were advised not to smoke or drink coffee before the test.

Participants were recruited with a flyer placed around the central campus of Stellenbosch University. The flyer can be seen in Appendix A. Subjects were selected on a first-come-first-serve basis if they met all the criteria in the table below.

Table 2: Inclusion and Exclusion Criteria for Participants

Inclusion	Exclusion
Individuals between the age of 18 – 25 years	Individuals using other medication that may affect dopamine release in the brain.
Diagnosed with ADHD/ADD	Individuals using immediate-release Ritalin or any short-acting medication that contains methylphenidate.
Have an active prescription and uses medication regularly	Participants that are unwilling to sign the consent form.
Participants with corrected vision problems.	Participants with hearing problems.
	A participant that is colour blind.

Two volunteers withdrew from the study leaving a remaining total of 11 individuals to complete the study. The individuals that withdrew from the study each completed one day of testing.

3.3 Neuroimaging Device

NIRSIT a product by Obelab is a functional near-infrared spectroscopy imaging system developed in Korea. NIRSIT is a device that measures variations in cerebral blood oxygen saturation by radiating a near-infrared light beam into the cerebral cortex (Obelab, 2018). The light beam consists of two wavelengths of 780 nm and 850 nm (Obelab, 2018).

This system allows for real-time measurements of the prefrontal cortex (Obelab, 2018). The device can record up to 204 channels on the prefrontal cortex whereafter software is used to monitor the distribution of cerebral oxygen saturation via multiple channels. The device is portable as well as lightweight with a weight of just 500g (Obelab, 2018). The software provides a mobile tablet-based user-friendly Graphical User Interface (GUI) for system control, real-time cortical 3D mapping of transient Oxy and De-oxy hemoglobin concentration variations, (Obelab, 2018). The NIRSIT system is shown in Figure 11.

Figure 11: NIRSIT (Obelab, 2018)

The device is specifically designed for the prefrontal cortex, which is the focus of this project as it is known to be impacted by ADHD. The maximum resolution of NIRSIT is 0.4 cm by 0.4 cm and is similar to functional MRI devices (Obelab, 2018). NIRSIT has a sampling frequency of 8 Hz and is an ideal solution for this project because of its high spatial and temporal resolution. The device is also relatively easy to use with not a lot of set-up time needed.

The channel distribution of NIRSIT across the prefrontal cortex can be seen in Figure 12. In the figure, it can be seen that NIRSIT covers the whole prefrontal cortex: dorsolateral, ventrolateral, frontopolar prefrontal cortex as well as the orbitofrontal cortex. In order to be consistent and achieve accurate results, NIRSIT was placed on the head just above the eyebrows with the nose tip in line with the centre of the device.

NIRSIT makes use of the modified Beer-Lambert Law to determine the density variation of oxy- and deoxyhaemoglobin, as explained in Chapter 2. The distance between sources and detectors is important as it has to do with the depth of penetration into the cortex. A deeper penetration means that deeper structures in the cortex can be explored. Research indicated that a separation between 2 cm and 3 cm is ideal (Gervain *et al.*, 2011). A distance of 3 cm was chosen between sources and detectors for this project.

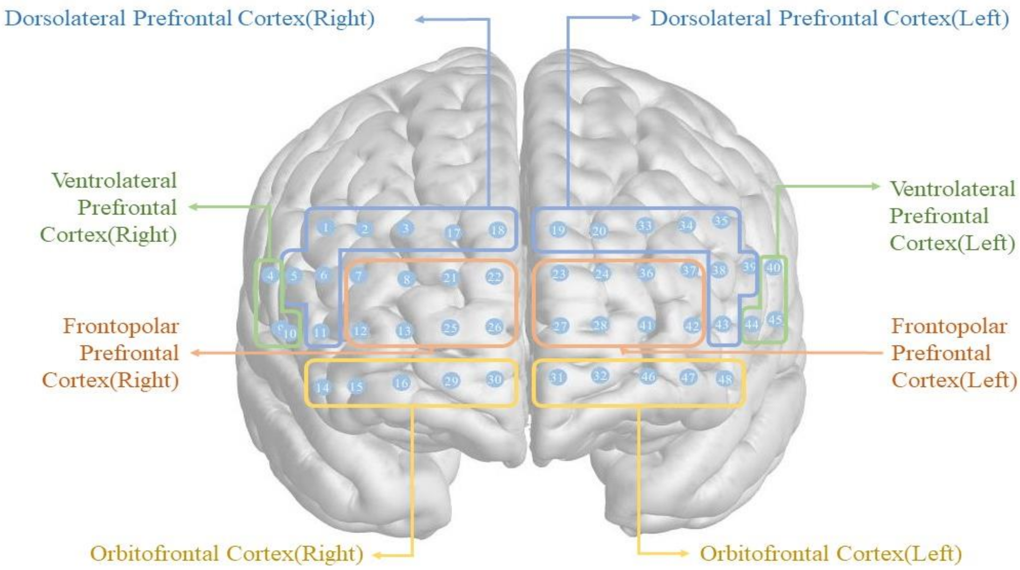


Figure 12: Channel Grouping (Obelab, 2018)

The device has its own analysing tool operating on MATLAB. The analysing tool was useful for this project as all the pre-processing of data was done using this tool. The tool had the possibility of applying filtering methods, selecting certain channels, viewing heat maps and extracting certain features to be analysed.

3.4 Music Selection

In this section, the music selected for the experiment is explained in detail.

3.4.1 Classical Music

Classical music has widely been studied as well as its effects on concentration. One of the most interesting discoveries was how classical music affects vocabulary retention. Georgi Lozanov (known as the "father of accelerated learning" studied a Spanish class, which was exposed to baroque music at 60 beats per minute in the background while the class learned vocabulary words (Weeks, 2011). The finding showed the children were able to learn two years of vocabulary in 30 days. Moreover, the retention rate of these words weeks later was almost 100%.

Classical music has been talked about over the years as a genre of music that has a range of effects from increasing purchases in shops to affecting memory and cognition (Bugter & Carden, 2012). Investigating and choosing the classical music pieces for the research presented a challenge as a whole range of classical music can be found. Ideally, the tempo should be controlled (tactus, the inter-onset interval of the pulse), rate-of-event-presentation (because a piece can have a slow tempo but high rate-of-presentation), timbre (the instrument, like keeping it just to piano pieces), time-period of composition (this is the ham-fisted control for style and consonance pitch) as well as the familiarity (e.g. using lesser-known pieces). Controlling all these parameters seems almost impossible.

Aiming to keep the instrument used in composition constant, it was decided to investigate classical music that contains the piano as the main instrument. Another study looked into the effects of musical genres on a memory task. In this study, individuals were exposed to rap music, classical music or silence while playing a concentration game, which requires flipping of cards to complete (Bugter & Carden, 2012). The classical music to which participants were exposed to was *Symphony No. 5 Piano Concerto in E-flat* by Beethoven. The study concluded that the group that was exposed to classical music completed the memory task in fewer flips compared to other groups (Bugter & Carden, 2012).

The study above indicated that *Beethoven Symphony No. 5* may have an effect on cognitive performance. It was decided to look into another study using the same composer as well as the same instrument. Beethoven's *Fur Elise* is another well-known piece. It was decided that the classical music in this experiment comprised of Beethoven's *Symphony No. 5 in E-flat* as well as *Fur Elise*. The compositions chosen are all from Western-style and are all well-known pieces.

3.4.2 Binaural Beats

Binaural waves were discovered by Heinrich Wilhelm Dove in 1839 (Crespo *et al*., 2013). Binaural Beats occur when two sinusoidal waves at different frequencies are presented separately to each ear, which is then normally experienced as a pulsating auditory sensation at different frequencies between two waves (Goodin *et al*., 2012). For example, if a 120 Hz tone is directed to the left ear and a 100 Hz tone directed to the right ear; the frequency difference between the two will be 20 Hz, and this is a binaural tone.

The binaural hearing beats occur in the brain stem as a response to auditory stimulation by two pure tones with slightly different frequencies, each in a different ear (Crespo *et al.*, 2013). Binaural auditory beats in the delta and theta frequency range are associated with enhanced creativity and improved sleep, while auditory beats in the EEG beta frequency range can enhance attention and memory task performance (Lane *et al.*, 1997).

Different studies found a positive relationship on attention tasks after binaural beat stimulation while other studies could not find a significant difference. A study done by Goodin *et al.* (2012) investigated whether binaural beat stimulation alters vigilance or cortical frequencies and if personality traits were involved. Participants were exposed to binaural beat stimuli designed to elicit a response in either the Theta (7 Hz) or Beta (16 Hz) frequency bands while undertaking a zero-back vigilance task. EEG was used to record brain activity.

In conclusion, statistical analysis of the experiment revealed that there were no significant changes in either reaction time in the Beta or Theta stimulation (Goodin *et al.*, 2012). This is contrary to the study conducted by Lane *et al* (1997), which indicated a significant difference. Another study was done by Crespo and Kennel (Crespo *et al.*, 2013; Kennel *et al.*, 2010) where both studies were unable to replicate results from Lane.

The study conducted by Lane *et al*. (1997) recruited volunteers from the Duke University community to participate in an experiment whereby they would be exposed to binaural beats in the beta or theta/delta range. Preliminary experimental studies suggest that binaural beats in the EEG beta frequency range can enhance performance during memory and attention tasks (Beauchene *et al.*, 2016; Garcia-Argibay *et al*., 2019; Lane *et al.*, 1997). In this study, they recruited 32 individuals with good health to listen to binaural beats in either the beta or theta/delta range. In the beta condition, a 200 Hz tone was presented in a 16 Hz and 24 Hz binaural beat (Lane *et al.*, 1997).

The participants were presented with a vigilance task while they were listening to binaural beats. In conclusion, the study found that participants detected a significantly larger number of targets in the vigilance task when exposed to beta-frequency binaural beats than binaural beats in the theta/delta range (Lane *et al.*, 1997).

Based on the findings by Lane *et al.* (1997), it was decided to recreate the binaural beat in the beta range and investigate its effects compared to other treatment conditions. The beat was created by using Audacity which is an open-source audio software program (Audacity, 2019). A binaural beat was created that swept between 16 Hz – 24 Hz with a base frequency of 200 Hz. The beat was 30 minutes long with a constant 200 Hz in the right ear and a variable beat of 216 Hz – 224 Hz in the left ear. Results obtained from this experiment can be compared to the experiment done by Lane *et al.* (1997).

3.4.3 Music of Preference

Most people listen to music they enjoy. The question to be asked is whether music of preference has a positive effect on cognitive ability? It is estimated that as of

June 2019, 68% of adults in the United States of America aged between 18 – 34 years old reported listening to music every day (Statista, 2019).

Nowadays, students all over campuses listen to music constantly. Adding music of preference to the selected few musical conditions to be investigated was decided upon the popularity among university students. Participants were requested to fill in music of preference form before testing begins, for the authors to create a playlist for each individual. The form can be seen in Appendix B.

The only requirements for each song/composition were that the individual has a strong preference for the song/composition, listened to it 10 times or more and that the songs/compositions are easily accessible. The variety of music selected by participants can be seen in Appendix C.

3.5 Cognitive Tests

The idea of concentration is simple but how concentration is defined is more complex. The system developed in this experiment measures the level of concentration by using the amount of time required to perform a task, as well as the accuracy of the task that requires attention. This section looks at different cognitive tests to determine the defined concentration.

E-Prime 3.0 psychology software (Psychology Software Tools, Pittsburgh, PA) was used to create cognitive tests for the participants to interact with. Four different tests were used in the experiment and the layout of each experiment can be seen below.

3.5.1 Stroop Test

Developed by J. Ridley Stroop in 1935, the Stroop test has been reported in numerous cognitive experiments. The Stroop test is also commonly known as the "Stroop Effect" and is used to assess the ability to inhibit cognitive interference that occurs when processing a certain stimulus feature impedes the simultaneous processing of a second stimulus attribute (Scarpina & Tagini, 2017). Previous literature also reports its application to measure other cognitive functions such as processing speed, working memory, attention and cognitive flexibility (Scarpina & Tagini, 2017).

The Stroop test has a colour written out in a different colour to the name. The participant is required to select the colour of the word but not the word. This test was created in E-Prime software and the participant was instructed to press the corresponding button matching the colour of the word. The test was approximately 8-minutes long and 50 responses were required. Figure 13 below shows the layout of the Stroop test as seen by the participant.

The Stroop test was suggested as a useful tool to measure prefrontal dysfunction for ADHD individuals (Negoro *et al*., 2010).

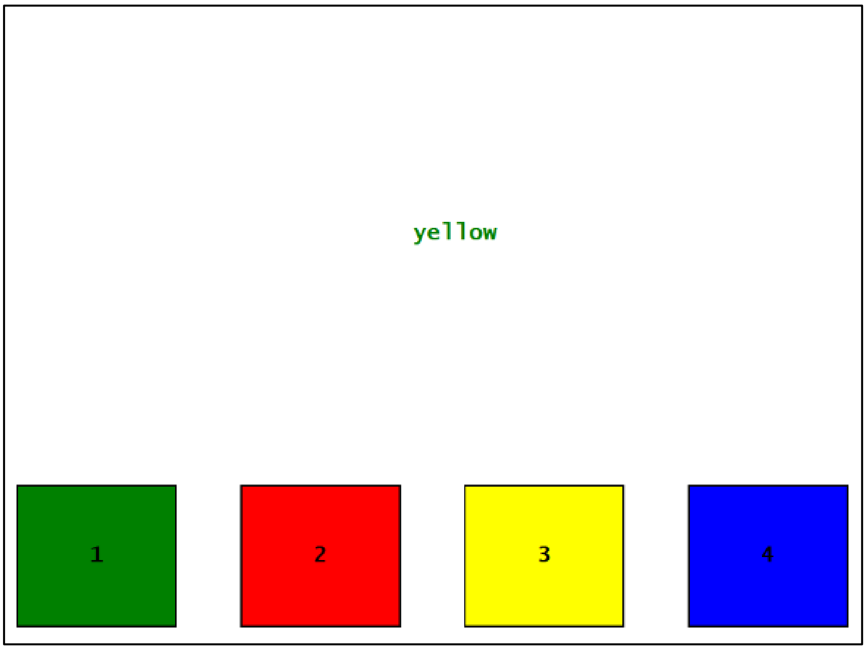


Figure 13: Example of Stroop Test

3.5.2 Sternberg Working Memory Test

The task required participants to memorise letters to be recalled at a later stage. In this test, short-term working memory is evaluated. The stages of memory are known to involve encoding, storage and finally retrieval (McLeod, 2013).

The participant was asked to memorize letters that were displayed on the screen in two different colours. Letters were continuously flashed to the participant for 16 seconds, allowing two seconds for each letter to be memorised. The letters in black needed to be memorised, while the letters in green should not be. Below in Figure 14, an illustration is given of the test.

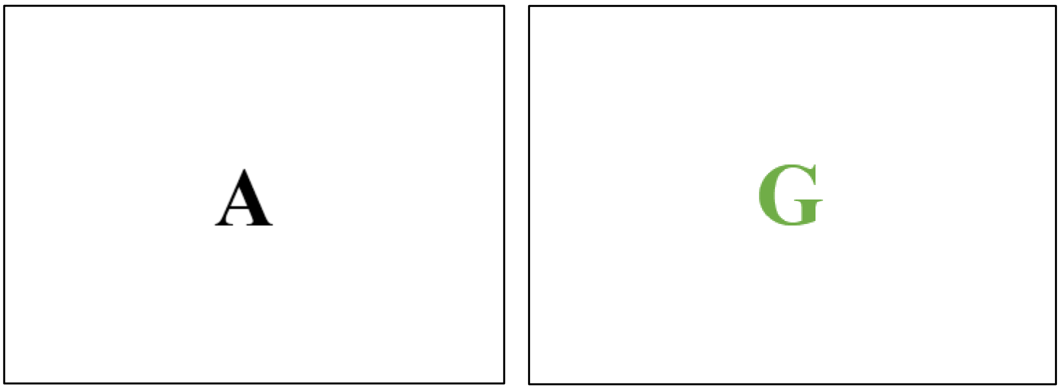


Figure 14: Sternberg Working Memory Test

After the letters were shown the participant was asked to recall the letters. In the recall, letters were shown in random order and the participant responded with either 1 if they were supposed to memorise the letter or 2, if they were not instructed to memorize the letter. In this test, memorisation accuracy can be determined.

3.5.3 Sustained Attention Test

The sustained attention test is a vigilance test. This test measures simple reaction time, general alertness and motor speed through presenting a stimulus to the participant and requiring the participant to react. In this test, participants were asked to press the space bar on a keyboard as soon as a black star appears on the screen. Participants kept their hands on the space bar at all times.

The main measure taken from this test was the speed of response to a stimulus.

3.5.4 Time Perception Test

Research indicates that individuals with ADHD perceive time differently than individuals without ADHD, but the exact nature of the impairment is still unclear (Meaux & Chelonis, 2003). Poor time perception affects the performance of social skills and other adaptive behaviours such as health consciousness and concerns for safety. A study was done by Meaux & Chelonis (2003) and found that children with ADHD had significant greater absolute discrepancy scores on a time reproduction task compared to a control group, $p < 0.01$. The research indicated that individuals with ADHD perceive time as moving more slowly than individuals without ADHD.

Brain regions that are associated with time perception, namely the prefrontal cortex, cerebellum and, basal ganglia, are key brain areas known to be impaired in ADHD (Smith *et al*., 2002). It is known that the right inferior prefrontal cortex and anterior cingulate have been shown to activate in fMRI studies during time estimation (Pedersen *et al.*, 1997).

In the experiment, the individual was asked to count for 10 seconds. Individuals were instructed to press the space bar as soon as they felt ready to count for 10 seconds in their heads where after they pressed the space bar again when they thought 10 seconds had passed. Data of the actual time passed was compared to the time counted by each participant in order to determine how close each participant counted to the actual 10 seconds.

The aim of this experiment was to investigate how time perception changes under different treatment conditions.

3.6 Experimental Setup

This section explains the experimental layout in more detail. All the experimental procedures were conducted in a dimly lit room in order to avoid light interference as functional near-infrared spectroscopy is sensitive to environmental light.

At the start of each testing session, each participant was asked to show a valid prescription indicating that they were diagnosed with ADHD/ADD and actively use medication. The principal investigator explained the study verbally in order to make sure the participants knew what to expect. Participants were then asked to sign the informed consent form. No watches were allowed as it may influence the time perception test.

Each participant was comfortably seated in front of a computer screen. A keyboard was also placed in front of the participant for them to respond to behavioural tests. In order to prevent any distraction, the participant was instructed to keep their attention focused in front of them at the screen.

The NIRSIT was placed on the head of the participant whereby the participant was instructed to sit as still as possible for approximately one minute. During that minute the participant was not stimulated to any auditory stimuli and calibration of the device was conducted.

After the first minute, the participant was instructed to relax and respond when stimuli were shown on the screen. In the control test, no auditory stimuli were played but during the treatment, test participants were confronted with the four treatment conditions. In the periods where there were no stimuli shown on the screen, a black screen was shown to relax the subject's eyes. This process was repeated among all participants in order to ensure consistency.

The principal investigator was seated behind the participant making sure data is collected as well as running the behavioural tests at different time intervals. Cognitive tests developed in E-prime (Psychology Software Tools, Pittsburgh, PA) were used to send markers to the collection software of NIRSIT via an IP address. Markers were time-stamped in the collected data. Markers gave the investigators an indication of when a certain cognitive test was shown to an individual.

The experimental setup can be seen in Figure 15 below. In the figure, two laptops were used. One laptop recorded fNIRS data while the other laptop was used to play music to the participants at a comfortable level. Music was played at a loudness level to which the participant normally listens to music. Earphones were used instead of headphones which normally have a better quality of sound but could not fit over the ears of participants wearing NIRSIT.

Figure 15: Experimental Setup

NIRSIT was placed on the head just above the eyebrows with the nose tip in line with the centre of the device. The placement of NIRSIT on the head of an individual can be seen in Figure 16 below.

Figure 16: NIRSIT Placement

The data collection software gave the investigator a real-time heat map of oxy, deoxy, and total-haemoglobin. This is a useful function as the investigator made observations during tests to be used when data analysis was conducted. The heat-map of real-time brain activity, as well as the recording software as seen by the investigator, can be seen in Figure 17 below.

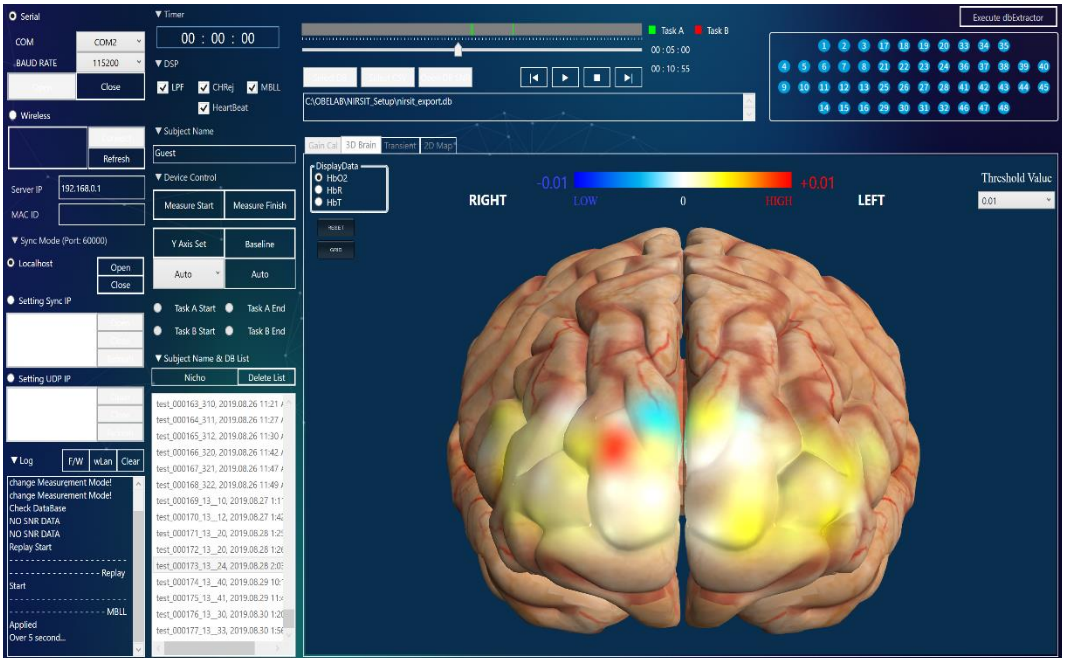


Figure 17: Recording Software with Real-Time Monitoring

At the end of each test, the participants were instructed to complete a feedback document seen in Appendix A 4. The feedback form was introduced to get the participant's opinion.

3.7 Near-Infrared Spectroscopy Data Analysis

This section explains the pre-processing as well as feature extraction of the collected near-infrared spectroscopy data.

3.7.1 Pre-processing

Raw data collected by NIRSIT was exported into a .csv file for further analysis. The analysis toolbox developed by NIRSIT running with MATLAB was used for data extraction. Firstly, the modified Beer-Lambert law was used to convert raw light intensities to concentration changes of oxy-haemoglobin, de-oxyhaemoglobin as well as total-haemoglobin.

The wavelengths of the raw light intensities were respectively 780 nm and 850 nm. The raw recorded data for 780 nm without any filtering can be seen in Figure 18 below. In the figure, raw data recorded by each channel can be seen.

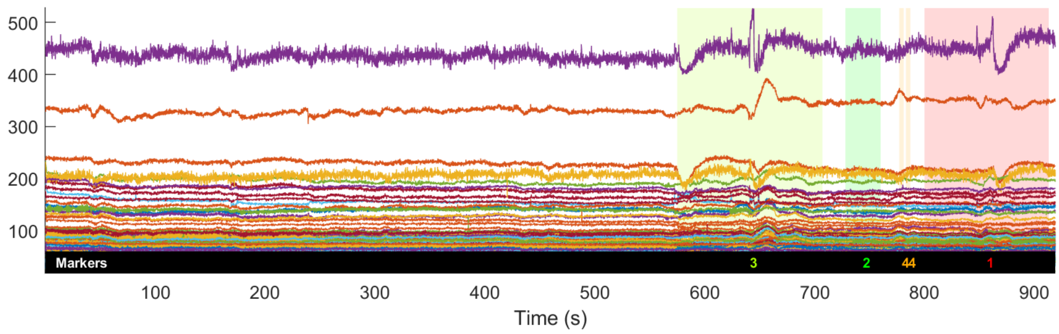


Figure 18: Raw Data (780 nm)

The figure is an example of a 30-minute test done by a participant. In the figure, the four different marker regions can also be seen. The marker regions correspond to a certain behavioural task. Marker one indicates the Stroop Test, two the Sternberg working memory task, three the sustained attention task and four the time perception test. Indicating markers in this way allows the investigators to visually look for certain patterns or features present.

As seen in Figure 18, data appears to be contaminated with noise. To remove spontaneous activities from the recorded NIRS signals different high and low pass filtering was applied. It was decided to use a low-Pass filter with DCT (Discrete Cosine Transform) transform and a high cut-off frequency of 0.02 Hz. The high-pass filter also consisted of a DCT transform with a low cut-off frequency of 0.002 Hz.

The filter was chosen to reduce artefacts such as heart rate, movement, and Mayer waves while retaining the maximum amount of information. Oscillations of arterial pressure are known as Mayer waves and this feature occurs spontaneously.

Physiological artefacts such as breathing and Mayer waves were observed at approximately 0.3 and 0.1 Hz while spontaneously physiological components of fNIRS have a frequency band of 0.01 and 0.09, (Hwang et al., 2014).

Figure 19 illustrates the filtered data. As seen in this figure a significant effect can be seen in comparison to Figure 18.

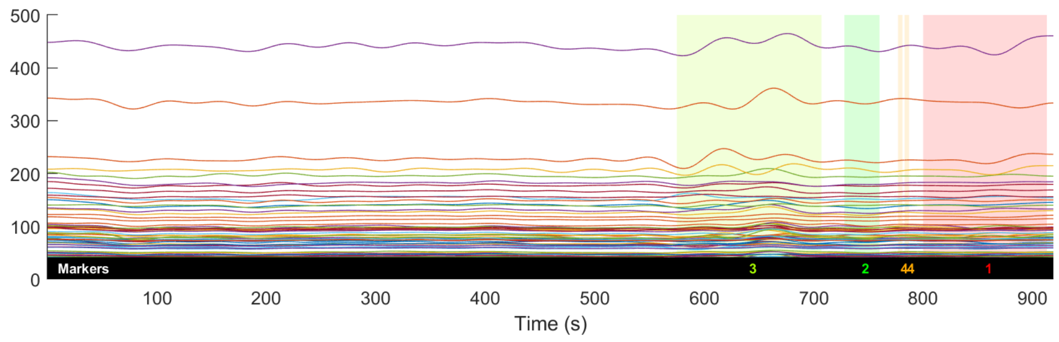


Figure 19: Data Filtered (780 nm)

After applying the above-mentioned filtering techniques, the modified Beer-Lambert law was applied to convert the raw data to oxy-haemoglobin, deoxy-haemoglobin and total-haemoglobin. The results for oxy-haemoglobin across all channels can be seen in Figure 20 below.

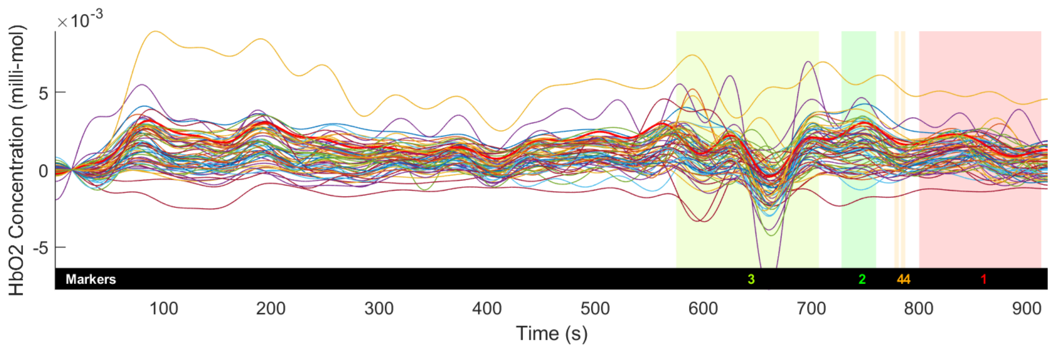


Figure 20: Oxy-Haemoglobin Concentration across Channels

The plot (seen in Figure 21) was used to decide which light intensity data, as well as signal to noise ratio (SNR) to use. This figure is an example of one test's recorded data.

The data in the figure is a plot of the SNR for each channel as well as for the two light ranges. It was decided to choose the SNR threshold at 30 dB represented by the grey area in Figure 21. This threshold was chosen as signals greater than 0 dB represents more signals than noise.

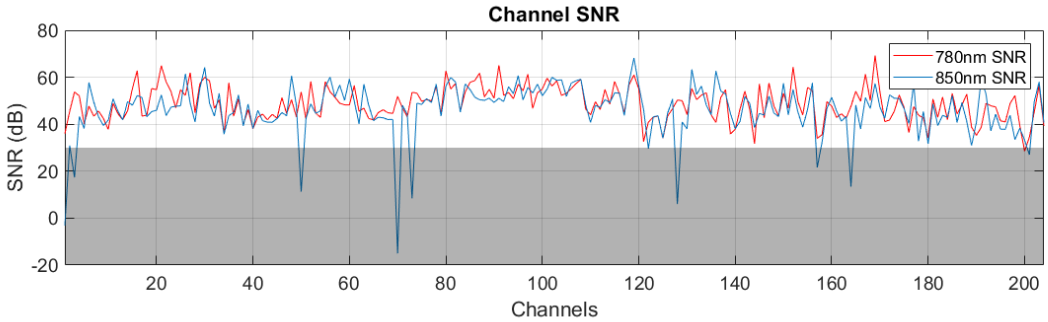


Figure 21: Channel SNR

Channels were rejected based on an SNR of 30 dB. This threshold was chosen as it removes most of the troughs, as seen by the blue line (850 nm). This particular participant had one channel rejected for a light intensity of 780 nm while 10 channels were rejected for 850 nm. The light intensity to be used in this project was decided to be 780 nm represented by the red line in the figure.

In general, across all tests for 780 nm four channels of the 204 channels recorded were rejected. Meaning that roughly 2% of channels were rejected based on the 30 dB threshold.

3.7.2 Feature Extraction

The average oxy-haemoglobin, deoxy-haemoglobin, and total-haemoglobin were calculated across all 204 channels for a specific marker period. Calculating the average haemoglobin concentrations avoids any assumption of the exact shape or timing of changes in haemoglobin in response to stimuli. Taking the average haemoglobin values over a predefined period for a certain task has been widely used in NIRS-based studies (Bauernfeind *et al*., 2011; Gervain *et al.*, 2011; Holper & Wolf, 2011; Hwang *et al.*, 2014; Sitaram *et al*., 2007).

Average data for each participant were extracted across all four markers for the duration of the behavioural task. A region of data in the control and treatment tests were isolated when a participant was shown no stimuli. This region was used to determine how active the prefrontal cortex was under each treatment condition. The region was manually isolated for each test looking at the region where the least amount of head movement was present. The region mentioned here is marker 10.

The average haemoglobin concentrations were exported to a .csv file for further analysis. In Appendix B, Table B 3 shows the average data calculated across all 204 channels for a behavioural task period. In the figure, the rejected channels based on the SNR threshold are indicated by a zero. A grand average across all the channels for all the behavioural tasks as well as M10 was calculated. The averages for the example in Appendix B can be seen at the bottom of the table.

In order to compare control (silence) with a treatment condition for each participant on each day, a difference between the grand average of the treatment and control tests was calculated. The differences were done for all the markers including marker 10. All the above-mentioned data were exported to be used for data analysis.

Head maps were also used to determine if it was possible to detect certain channels or regions of the prefrontal cortex to light up during certain tasks. However, this technique did not find any obvious differences. Therefore, the activation of the prefrontal cortex as a whole was the focus of the data analysis procedure.

4 Results

As mentioned previously, 11 volunteers participated in this study two withdrew. The participants that withdrew from the study each completed one day of testing. In total, 46 hours of haemoglobin response data across the prefrontal cortex was collected.

In this chapter, the data collected from NIRSIT, four behavioural tasks, as well as feedback from participants, are analysed.

4.1 Comparison of Oxy-Haemoglobin across Mental Tasks

Statistical data analysis software was used to conduct data analysis. Factorial Analysis of variance (ANOVA) was applied to the haemoglobin response data. It was decided to use factorial ANOVA as more than three results can be compared against one another. Furthermore, a p-value smaller than 0.05 would indicate statistically significant results.

The average differences (treatment from control) for oxy-, deoxy- and total-haemoglobin were extracted in order to determine the method that induced the greater change in activity across the four tasks in the prefrontal cortex. A more positive average value would thus suggest increased activation. The mean difference in oxy-haemoglobin, deoxy-haemoglobin, and total haemoglobin was compared against one another for each behavioural task.

Oxy-haemoglobin results indicated an overall difference of $F(4,60) = 2.01$ and $p = 0.10$ compared to deoxy-haemoglobin ($F(4,60) = 0.12$; $p = 0.97$) and total-haemoglobin ($F(4,60) = 1.71$; $p = 0.15$). Based on these results, it was decided to compare mean results obtained from oxy-haemoglobin as analysis indicated by a smaller p-value. The Shapiro-Wilk test was done to confirm that the difference in HbO_2 data is normally distributed and can be seen in Figure B 1 in Appendix B.

In order to determine whether an HbO_2 activation difference exists between different cognitive tests, the following plot of HbO_2 was created. The main reason for the plot in Figure 22 was to establish whether a certain behavioural test was responsible for greater haemoglobin activation. The plot in Figure 22 is across all music and medication conditions. The mean difference in oxy-haemoglobin was plotted as well as the confidence interval.

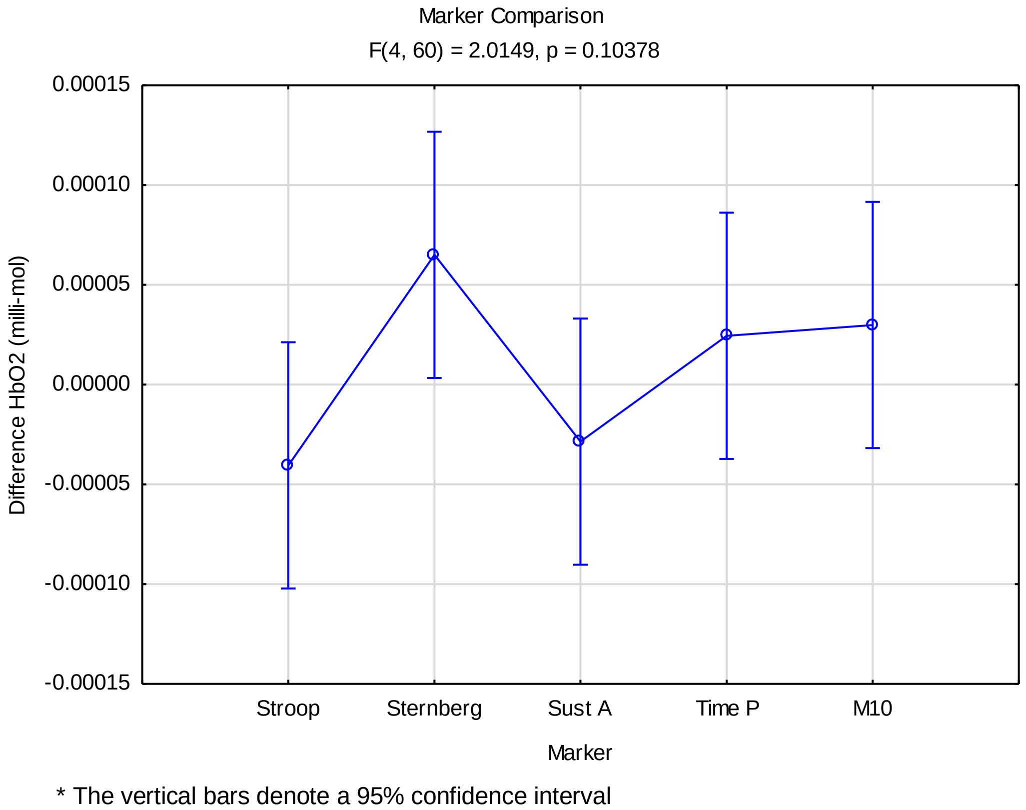
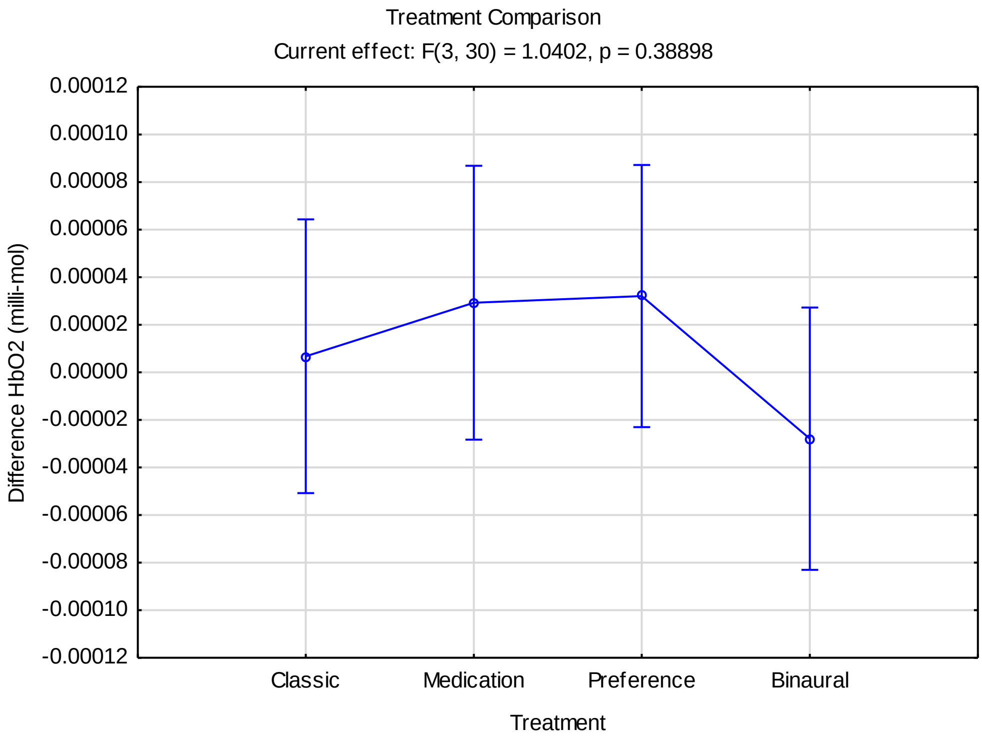


Figure 22: Marker Comparison

As seen in Figure 22, no significant effect was observed as an overall p-value of 0.10 was calculated. Therefore, in general, no significant effect was observed when comparing different cognitive tests and marker 10 (M10) to one another. This suggests that no cognitive test was responsible for inducing greater activity in the prefrontal cortex overall.

It was theorized that a different treatment condition may be responsible for higher haemoglobin activation in the prefrontal cortex. Marker 10 (M10) is a period that was manually isolated for each test looking at the region where the least amount of head movement was present. The mean difference (treatment from control) was calculated and the plot of the repeated measures factorial ANOVA can be seen below in Figure 23. No significant difference (F (3,30) = 1.04; p = 0.39) was detected comparing mean HbO_2 activation for classical music, medication, music of preference as well as binaural beats.



* The vertical bars denote a 95% confidence interval

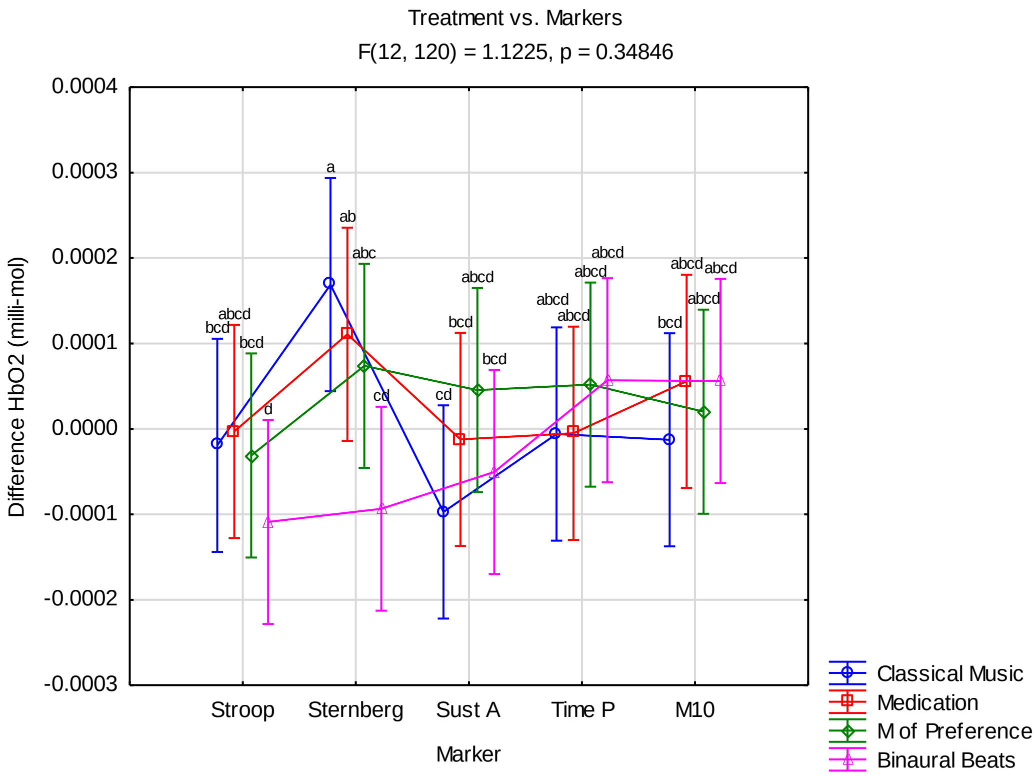
Figure 23: Treatment Comparison

Finally, to compare different treatment conditions across different tasks the following plot was created as seen in Figure 24. The results displayed in the figure were obtained by performing repeated measures factorial ANOVA with four treatment conditions (classical music, music of preference, binaural beats, medication) by five cognitive tasks (Stroop-, Sternberg working memory-, Sustained attention-, time perception- test) as well as M10.

As in the previous figure, the vertical bars denote the confidence interval, while the average HbO_2 mean difference (treatment from control) was plotted. In the figure, the four connected lines indicate a treatment condition while the x-axis displays the cognitive tasks. The small letter subscripts above each confidence interval denote the statical significance for a specific marker.

Although in general no overall significant difference ($F(12,120) = 1.12$; $p = 0.35$) was observed as seen in Figure 24, the mean difference values are seen to form a pattern giving an indication that it is possible to look at the main effects.

The same could not be said of deoxy-haemoglobin (HbR) data. Figure B 2 in Appendix B indicates that no visual pattern can be seen. The p-value is also larger for deoxy- and total-haemoglobin. It is therefore not possible to look at the main effects; thus, only the oxy-haemoglobin data was analysed.



* The vertical bars denote a 95% confidence interval, while the small letter subscripts above each confidence interval denote the statical significance for a specific marker. Similar letters indicate no difference while different letters indicate a p-value of less than 5%.

Figure 24: Treatment vs. Markers Oxy-haemoglobin

As the difference was taken between the treatment test and control test a positive value will indicate more HbO_2 directly related to more activity. The Stroop test is the first to be analysed. No overall significant difference was observed between different treatment conditions. Although the average HbO_2 concentrations were lower when a participant listened to binaural beats.

In the Sternberg working memory task, classical music and binaural beats had a significant difference of $p = 0.003$ in oxy-haemoglobin activation. Classical music resulted in more activity in comparison to binaural beats. A difference of $p = 0.05$ was observed between the music of preference and binaural beats. This result approaches statistical significance indicating music of preference resulted in a greater HbO_2 activation.

Another difference was also picked up between medication and binaural beats of $p = 0.02$. Indicating that medication and classical music were responsible for greater oxy-haemoglobin concentrations during the Sternberg working memory task.

The sustained attention test did not produce any significant results and therefore no difference was observed. Moreover, no significant difference was observed between oxy-haemoglobin for the time perception test.

The marker known as M10 was introduced in aiming to determine how active the prefrontal cortex was under different treatment conditions without any cognitive tests. The results indicate no significant difference.

4.2 Behavioural Data

This section analyses the responses of individuals for the four different cognitive tests. In the section, all the parameters measured at each cognitive test will be explained. Data analysis was done through repeated measures using factorial ANOVA.

4.2.1 Stroop Task

In this test, the accuracy as well as the reaction time, were recorded. Data was also tested for normality by using the Shapiro-Wilk test. The data were normally distributed.

The reaction time recorded how fast the individual responded to a task. Differences for the reaction time were calculated by subtracting the control time from the treatment time. The same was done with the percentage accuracy. Meaning that a greater positive difference in reaction time indicates a positive improvement, while a greater negative difference in percentage accuracy indicated an improvement. The percentage accuracy was represented by the percent of correct responses made by a participant.

ANOVA was conducted on reaction time as well as with the four treatment conditions (classical music, music of preference, binaural beats, medication). The following table displays the reaction time results from the four treatment conditions:

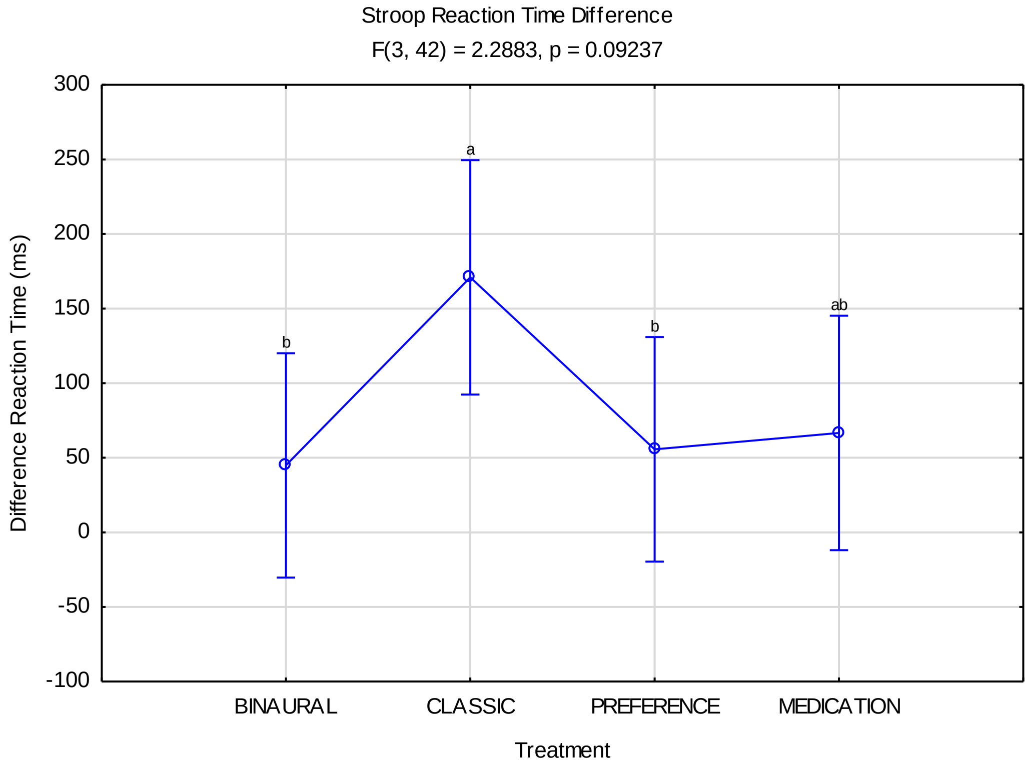
Table 3: Stroop Reaction Time

Treatment	N	Difference Reaction Time Mean (ms)[a]	Std.Dev.
Binaural	12	44.91	105.81
Classic	11	171.00	214.98
Preference	12	55.66	84.05
Medication	11	66.64	61.20

[a] Reaction time difference was calculated between control and treatment conditions. Indicating a smaller number would negatively affect reaction time.

The mean and confidence interval are plotted below in Figure 25. Overall no statistically significant effect (F (3.42) = 2.29; p = 0.09) was observed. Although significant partwise differences exist between treatment conditions. Binaural beats differ from classical music (p = 0.02), thus, indicating that classical music positively affected reaction time compared to binaural beats.

Classical music also differs from music of preference with p = 0.04. Indicating that music of preference negatively affected reaction time during the Stroop task in comparison to classical music. The difference between classical music and medication is p = 0.06; the result is marginally significant and on a trend of significance. No differences exist between binaural beats, medication, and music of preference.



* The vertical bars denote a 95% confidence interval while the small letter subscripts above each confidence interval denote statically significance for a specific marker. Similar letters indicate no difference while different letters indicate a p-value of less than 5%.

Figure 25: Stroop Reaction Time

Comparing accuracy improvement during the Stroop task for a participant under the four treatment conditions proved to result in no statistically significant results. The mean difference percentage accuracy, as well as the confidence intervals, can be seen in Appendix B. A summary of the accuracy for each treatment condition can be seen below in Table 4; exhibiting that binaural beats negatively affected accuracy but the result was not significant.

Table 4: Stroop Mean Accuracy

Treatment	N	Difference Mean Accuracy (%)[a]	Std.Dev.
Binaural	12	0.42	3.08
Classic	11	-0.45	4.23
Preference	12	-1.15	2.74
Medication	11	-0.05	2.77

[a] Mean accuracy difference was calculated between control and treatment conditions. Indicating a smaller number would positively affect accuracy.

In general, classical music tends to positively affect reaction time during the Stroop test, while binaural beats had the opposite effect.

4.2.2 Sternberg Working Memory Task

In this test, the percentage error in recalling memorised words was measured. The Shapiro-Wilk test was also used to confirm normally distributed data. The error differences were calculated by subtracting the percentage accuracy of the control test from that of the treatment test; meaning a lower mean accuracy difference value would indicate a positive treatment method. A factorial ANOVA analysis was done on the percentage error for each treatment condition. A summary of the results can be seen below in Table 5:

Table 5: Sternberg Accuracy Difference

Treatment	N	Difference Mean (ms)[a]	Std.Dev.
Binaural	12	1.04	5.56
Classic	11	0.76	5.53
Preference	12	0.69	5.85
Medication	11	-1.89	5.70

[a] Reaction time difference was calculated between control and treatment conditions. Meaning a lower number would indicate an improvement in percentage error.

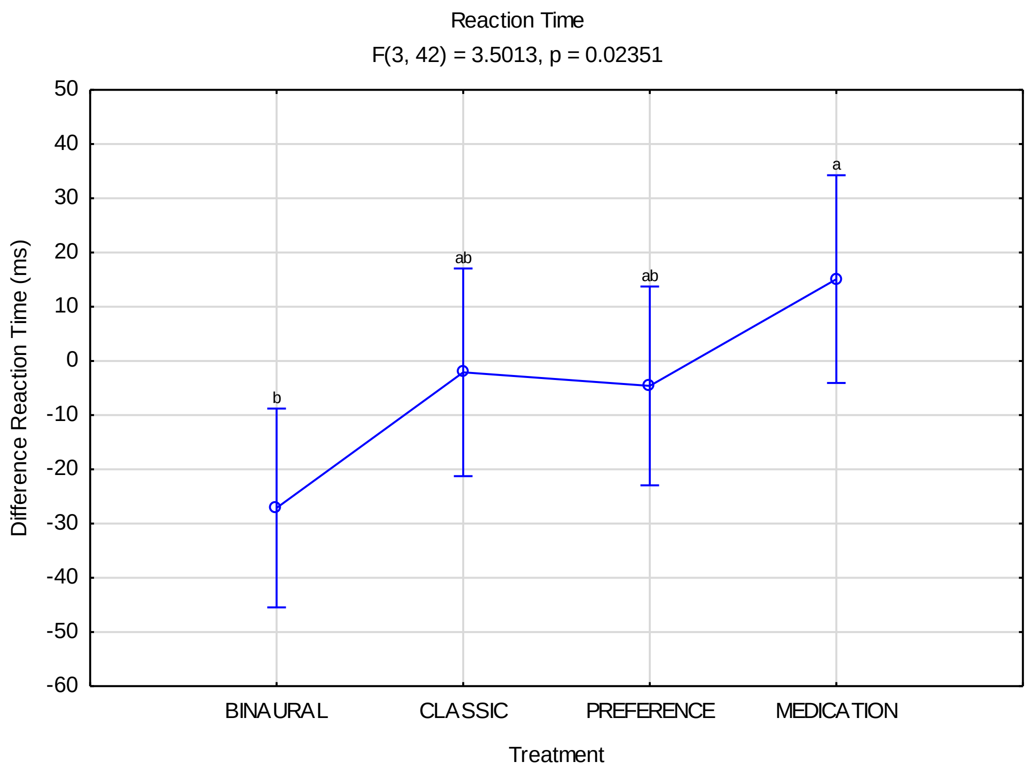
The results from the analysis did not indicate any significant differences ($F(3,42) = 0.65$; $p = 0.59$) between treatment conditions. The plot of the ANOVA results can be seen in Figure B 5, Appendix B. Although in the table above medication showed an improvement in percentage error but not significant enough.

4.2.3 Sustained Attention Task

The task measured the time an individual reacted to a stimulus shown on a computer screen. In this task, the participant's ability to focus on an activity over a period of time under each treatment condition was investigated. Reaction time was measured and the difference between control and treatment was taken; indicating that a greater mean reaction time difference indicates an effective treatment method. The data were tested for normality with the Shapiro-Wilk test. A factorial ANOVA was completed among the reaction time for each of the treatment condition.

The reaction time differences under each treatment condition can be seen in Figure 26 below. As seen in the figure below, results overall differ significantly (F (3,42) = 3.50; p = 0.02); indicating that there exist differences between treatment conditions.

No differences were observed between classical music, music of preference and medication. Medication differs significantly in comparison to binaural beats (p = 0.003) as seen by the small letter subscript in the figure. Therefore, the results indicate that medication positively affected reaction time compared to binaural beats.



* The vertical bars denote a 95% confidence interval while the small letter subscripts above each confidence interval denote statically significance for a specific marker. Similar letters indicate no difference, while different letters indicate a p-value of less than 5%.

Figure 26: Reaction Time

Figure 27 compares the mean reaction time of the binaural beats control test to the mean binaural treatment test. Binaural beats were isolated as an overall ANOVA analysis indicates that binaural beats significantly differ from medication.

As seen in Figure 27, the mean reaction time in milliseconds as well as the confidence interval were plotted for both binaural control and control. The result indicates a significant difference between the parameters (F (1,11) = 21.90; p = 0.0007). Results show that when the participant listened to binaural beats the reaction time was longer in comparison to silence. Therefore, the ability to focus on a stimulus over a period of time was negatively affected by binaural beats.

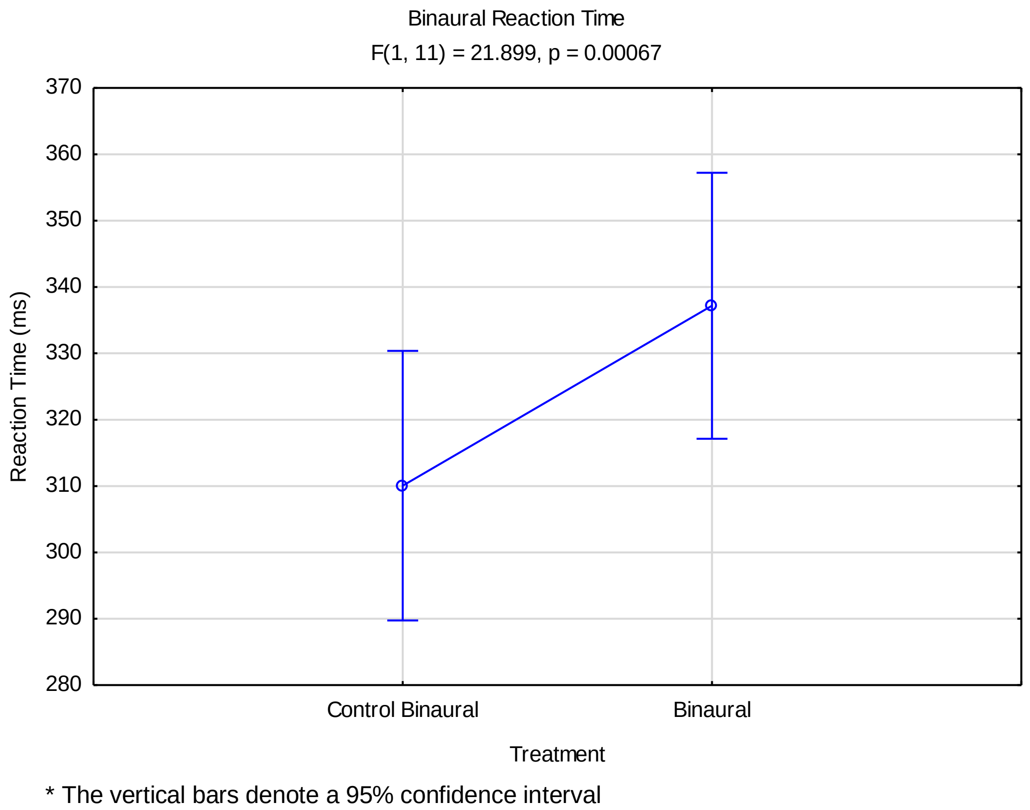


Figure 27: Binaural Reaction Time

A summary of the mean difference results can be seen in Table 6 below. The raw results collected for the reaction times for each participant can be seen in Table B 2, Appendix B. In the table, the reaction times as well as the average reaction times across treatment tests can be seen in milliseconds. Binaural beats have a mean reaction time of 337,17 milliseconds while medication had a mean of 307.44 milliseconds. In conclusion, the results indicate that binaural beats negatively affect reaction time, while medication has been proven to increase reaction time.

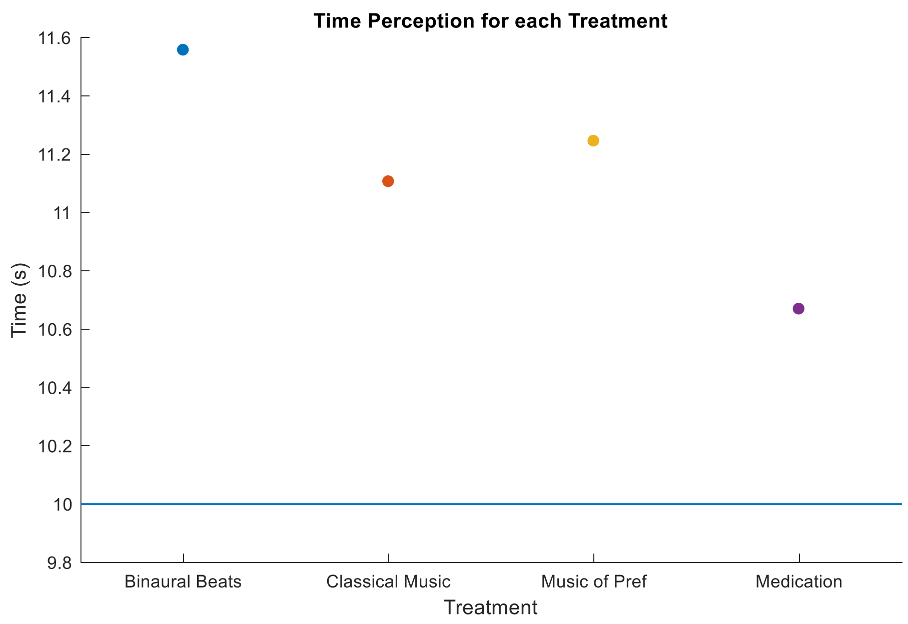
Table 6: Sustained Attention Reaction Time

Treatment	N	Difference Mean (ms)[a]	Std.Dev.
Binaural	12	-27.12	20.08
Classic	11	-2.11	31.26
Preference	12	-4.61	19.53
Medication	11	15.09	48.18

[a] Reaction time difference was calculated between control and treatment conditions. Indicating a smaller number would negatively affect reaction time.

4.2.4 Time Perception Task

The accuracy of each participant counting to 10 seconds under a different treatment condition was evaluated. The aim of this task was to determine the treatment method resulting in the most accurate result. Below in Figure 28, the mean actual values in seconds for participants were plotted against each treatment condition. The solid line at 10 seconds indicates the target time. As seen in the figure, the results only differed with a few seconds. Binaural beats were responsible for the greatest deviation from the target, while medication came close to the target.



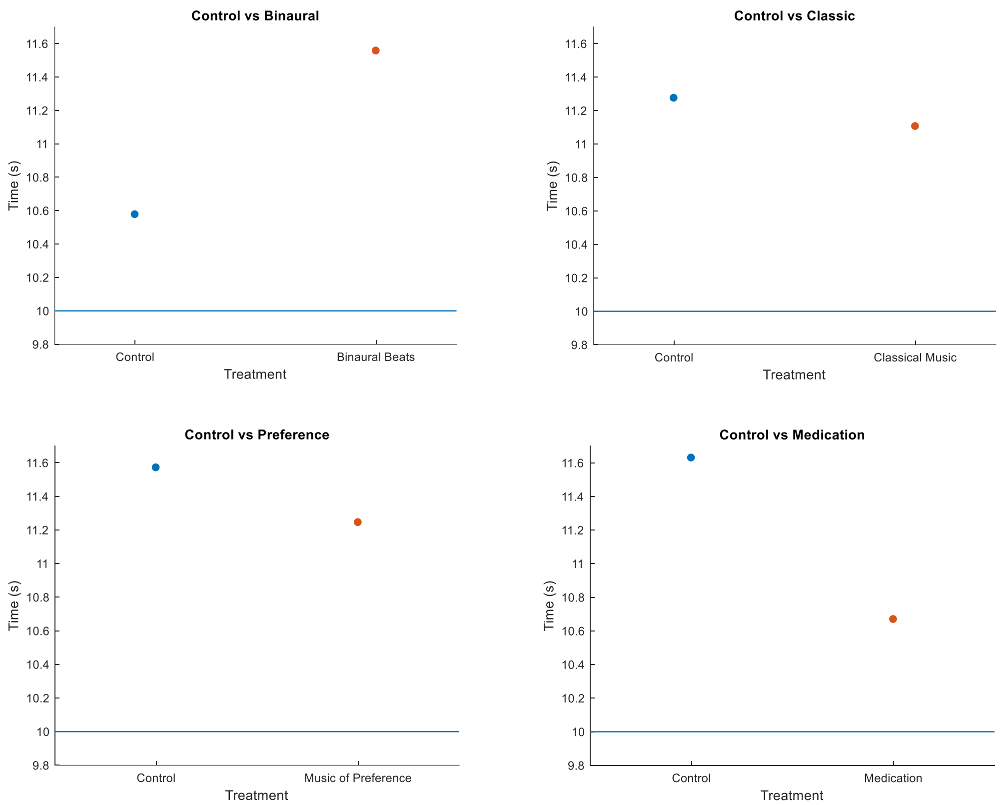
* The solid line at 10 seconds indicates the target time

Figure 28: Actual Time Perception for each Treatment

The raw data collected for each participant can be seen in Appendix B. Figure 29 visually presents the difference between mean accuracy for each treatment test as well as the corresponding control. As seen in the figure, the binaural beats were responsible for the greatest difference between silence (control) and medication.

All the treatment methods had a positive impact on time perception except binaural beats; as they negatively influenced time perception. Furthermore, the mean control time for each treatment test differed. Although, the tests were on different days and other factors could have influenced control time.

In order to determine if a difference exists between different treatment tests, the mean difference was calculated by subtracting the mean control time from the mean treatment test time. Indicating that a higher positive difference would indicate that the treatment method resulted in a shortened mean time perception. Thus, the treatment method had a positive effect on time perception.



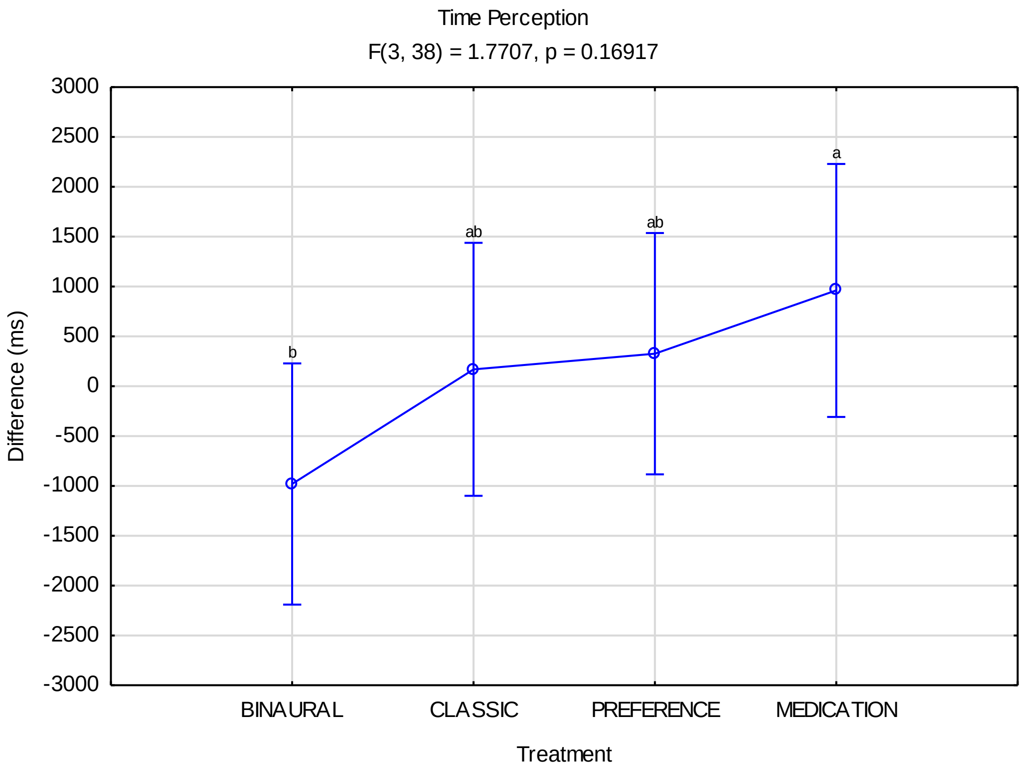
* The solid line at 10 seconds indicates the target time

Figure 29: Time Perception Control vs Treatment

The normality of data was also confirmed by the Shapiro-Wilk test. Factorial ANOVA analysis was applied to the mean differences. In general, no statistically significant result ($F (3,38) = 1.77$; $p = 0.17$) was observed across ANOVA as seen at the top of Figure 30.

The pairwise comparison between binaural beats and medication revealed a difference of $p = 0.03$. This difference indicates that the mean difference between the two conditions differs significantly. Medication had a great mean difference due to the longer time counted during the control compared to the treatment. Therefore, results show that medication had the most powerful effect on time perception.

Binaural beats, classical music and music of preference indicated no significant difference whereby medication, classical music and music of preference also did not indicate a difference.



* The vertical bars denote a 95% confidence interval while the small letter subscripts above each confidence interval denote statically significance for a specific marker. Similar letters indicate no difference while different letters indicate a p-value of less than 5%.

Figure 30: Time Perception

Overall, the results indicated no significant difference although medication indicated to have the most powerful/positive result on improving time perception. A summary of the results can be seen in Table 7 below.

Table 7: Time Perception

Treatment	N	Difference Time Perception (ms)[a]	Std.Dev.
Binaural	11	-980.66	1283.13
Classic	10	169.20	1948.04
Preference	11	326.09	2524.54
Medication	10	961.30	1971.36

[a] Reaction time difference was calculated between control and treatment conditions. Indicating a smaller number would negatively affect time perception.

4.3 Participant Feedback

Participant feedback was recorded using the post-completion survey form seen in Appendix A4. The feedback form was introduced into the study to get a feel of the participants' experiences. The experience of different treatment conditions is important as the music that a person dislikes usually causes irritation and negatively affects concentration.

The participants were asked to rate the music out of five; five showed they enjoyed it, while one indicated a dislike. Figure 31 illustrates the results obtained when participants were asked to rate the musical experience of the three musical conditions.

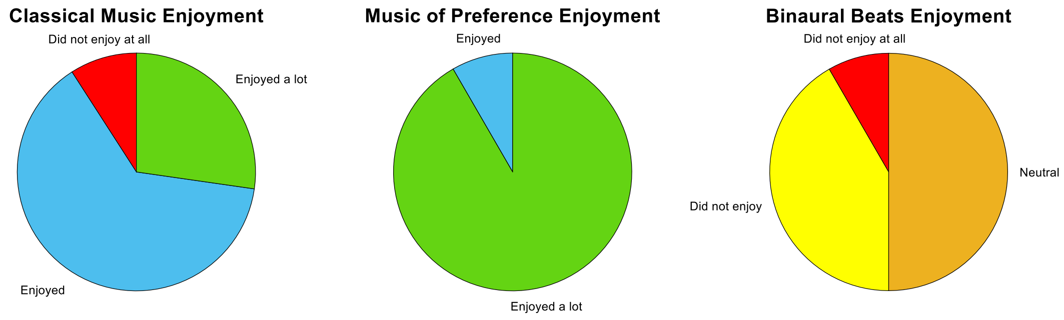


Figure 31: Musical Enjoyment

In general, the enjoyment of classical music was positive while for binaural beats the overwhelming feeling was neutral. As expected, music of preference was enjoyed by participants. Music of preference included a variety of musical genres from rock to pop; the list of song tracks can be seen in Appendix C.

Participants were also asked to rate the ability for them to concentrate under each treatment condition as well as the control test. Comparing results from NIRSIT and cognitive tests as well as participants' feedback could shed some light on how concentration is influenced by different treatment tests.

In Figure 32, the ability for participants to concentrate when exposed to a musical treatment test can be seen. As seen in the figure, classical music compared to music of preference and binaural beats was rated as the musical condition to increase the ability to concentrate. Again, the overall feeling of binaural beats was neutral, while 25% indicated that music of preference and binaural beats created a distraction.

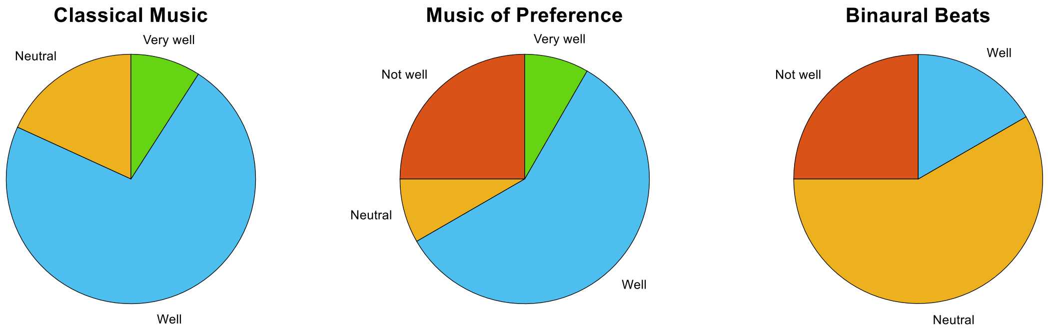


Figure 32: Ability to Concentrate on Musical Conditions

The ability to concentrate under medication as well as the control (silence) results can be seen in Figure 33. The overall feeling for silence was neutral keeping in mind that 77% of participants indicated that they listen to music when studying. The ability to concentrate after the medication was taken proved to be positive; more than 80% of the participant indicated that medication increased the ability to concentrate.

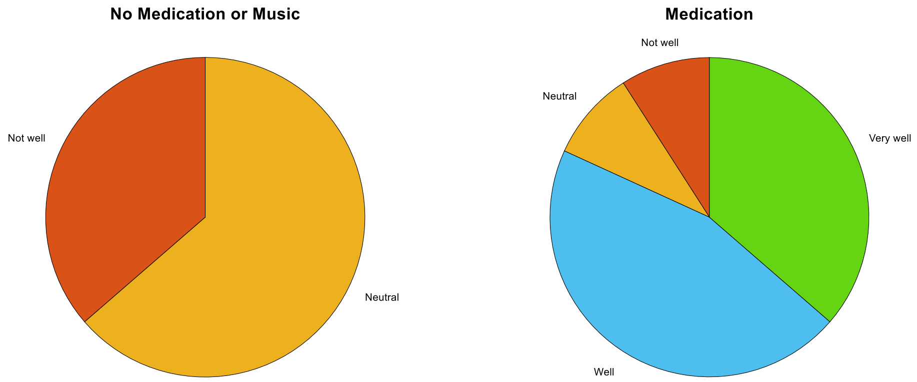


Figure 33: Ability to Concentrate

Participants' comments stated that they felt a calming/relaxing effect when they were listening to classical music. The participants felt that NIRSIT caused discomfort, thereby leading to a loss of concentration. Participants also indicated that listening to personal selection was enjoyable but it made it difficult to concentrate as they wanted to sing and move along with the music. Binaural beats were perceived as being annoying and not nice to listen to.

5 Discussion

Findings suggest that different music types, as well as medication, were not responsible for any overall significant activation across the prefrontal cortex. The major finding of this study was observed from the behavioural data. In the sustained attention task, medication outperformed binaural beats. Furthermore, binaural beats were also found to negatively affect attention in comparison to silence.

The main objective of this project was met by investigating different musical types as well as medication and its effect on concentration for ADHD individuals. In aiming to achieve this objective, the effects of oxy-haemoglobin, deoxy-haemoglobin and total-haemoglobin during the performance of several well-validated concentration tasks, behavioural data, as well as participants' subjective feedback, were taken into account.

Oxy-haemoglobin (HbO_2) was found to be more likely to be influenced by different treatment conditions in comparison to deoxy-, and total-haemoglobin. This is somewhat expected as an increase in activation across the prefrontal cortex is closely related to an increase in oxy-haemoglobin. In most cases, oxy-haemoglobin increased and deoxy-haemoglobin decreased during behavioural tasks. Analysing oxy-haemoglobin was also found by another study to induce greater differences (Nguyen, Hong & Shin, 2016).

No overall significant differences in haemoglobin activation across the prefrontal cortex was observed when the participant was on medication or listened to music (classical music, music of preference, binaural beats). Although post hoc comparisons of the main effects revealed that classical music and medication compared to binaural beats resulted in greater oxy-haemoglobin activation in the Sternberg working memory task. Prior to the study, it was expected that medication would result in an overall increase in prefrontal activation.

The analysis of the mean oxy-haemoglobin for each behavioural task duration did not indicate any significant difference when comparing behavioural tasks to one another. The working memory task was found by another study to be responsible for higher oxy-haemoglobin activation in the prefrontal cortex of ADHD individuals, (Moser *et al.*, 2009).

However, the results do not agree, which could be due to the other behavioural tasks to be equally impacted by ADHD. Another possible reason could be due to habituation; whereby the participant got used to the cognitive tests although the order of presentation was randomized. The Stroop test, as well as the Sternberg working memory test, were created to present stimuli at random to the participant.

Although haemoglobin activation during the Stroop task did not indicate a significant difference, the behavioural data of this task tell a different story. Overall, no significant effect was observed in behavioural data but the post hoc comparisons of the main effects indicated differences.

Individuals exposed to classical music performed significantly better in the Stroop task when compared to music of preference as well as binaural beats. Contrary to what was initially expected, classical music increased reaction time during the Stroop task in comparison to medication with a p-value of 0.06.

The p-value is not significant but on-trend to converge to the significance and therefore increasing the sample size may result in a significant difference. This result means that classical music can potentially result in better performance in comparison to medication, although medication is designed to improve attention. Binaural beats were found to negatively influence performance during the Stroop task.

Majority of participants in this study complained about the unpleasant sound of these beats, thus, the result is not unexpected. to the results are also supported by the conclusion of Huang and Shih (2011) that the listener's fondness of the music is likely to impact attention. The results agree that performance was negatively influenced by binaural beats.

Overall, classical music positively influenced reaction time during the Stroop test. The results confirm that classical music positively improves the ability to inhibit cognitive interference.

The behavioural data indicates that no significant difference exists in memorisation accuracy for the Sternberg working memory task. Thus, the results contradict Bugter and Carden’s (2012) findings that Beethoven *Symphony No.5* resulted in participants to complete a memorisation task with greater accuracy.

A possible explanation for this could be that the study from Bugter and Carden (2012) didn’t look at ADHD patient’s specifically. Another reason could be due to the difference in the memorisation task. Bugter and Carden (2012) made use of a concentration task by placing a deck of memorization cards on a table and instructing the participant to memorise the cards, while this study required participants to memorize letters in a short amount of time.

It was also noted during observations made in the experimental phase, that participants started to relax when they were confronted with cognitive tests they have completed before. The reason could be that the tests did not result in a big enough challenge for the individual. In Figure 34 below, the head movement recorded for one participant is shown during a test. Note that as time progressed head movements started to increase. The red line indicates left to right movement while the blue line indicates back to front movement of the head. This could be an indication that individuals got distracted as time passed. ADHD individuals have been known to get easily distracted (Barkley, 1998).

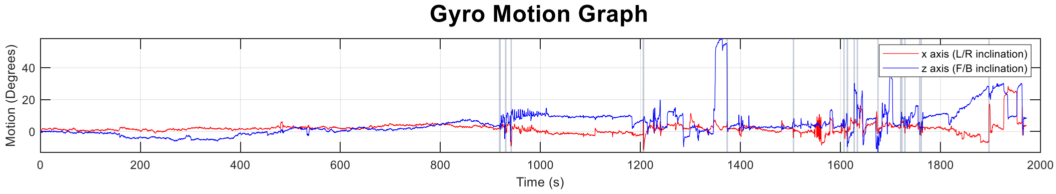


Figure 34: Gyro Motion Graph

Post hoc comparisons of the main effects of oxy-haemoglobin across the working memory task, indicated that classical music, music of preference and medication were responsible for higher haemoglobin concentrations in comparison to binaural beats. A possible reason why oxy-haemoglobin activation differences were identified across the Sternberg working memory task, could be due to the complexity of the task.

The Sternberg memory task can be seen as the most challenging of the four cognitive tests. As explained in the literature chapter, Lehmann and Seufert (2017) suggested that memory capacity is limited. If the individual's memory capacity is high enough, the individual will have sufficient capacity to invest in learning tasks after processing the auditive information. This could explain why individuals presented with higher oxy-haemoglobin concentrations as auditive information required processing as well.

The figure (Figure 35) shows heat maps of the prefrontal cortex for all the four treatment conditions during the Sternberg working memory test for a specific individual. The heat maps were taken at the same time during each test.

The colours in the figures indicate oxy-haemoglobin concentrations. A positive value indicates an increase in oxy-haemoglobin, while a negative value the opposite. In the figure, binaural beats were responsible for greater activity.

This particular individual complained that binaural beats made it harder to concentrate and therefore an explanation as to why activation may be higher compared to the other treatment methods.

In contrast, music of preference was not responsible for any significant activation. The results from this individual are contradicting to our findings of the combined oxy-haemoglobin across all participants. The results from this study indicated that binaural beats were responsible for least amount of oxy-haemoglobin activation. Indicating that an increase in oxy-haemoglobin activation is not always a good thing.

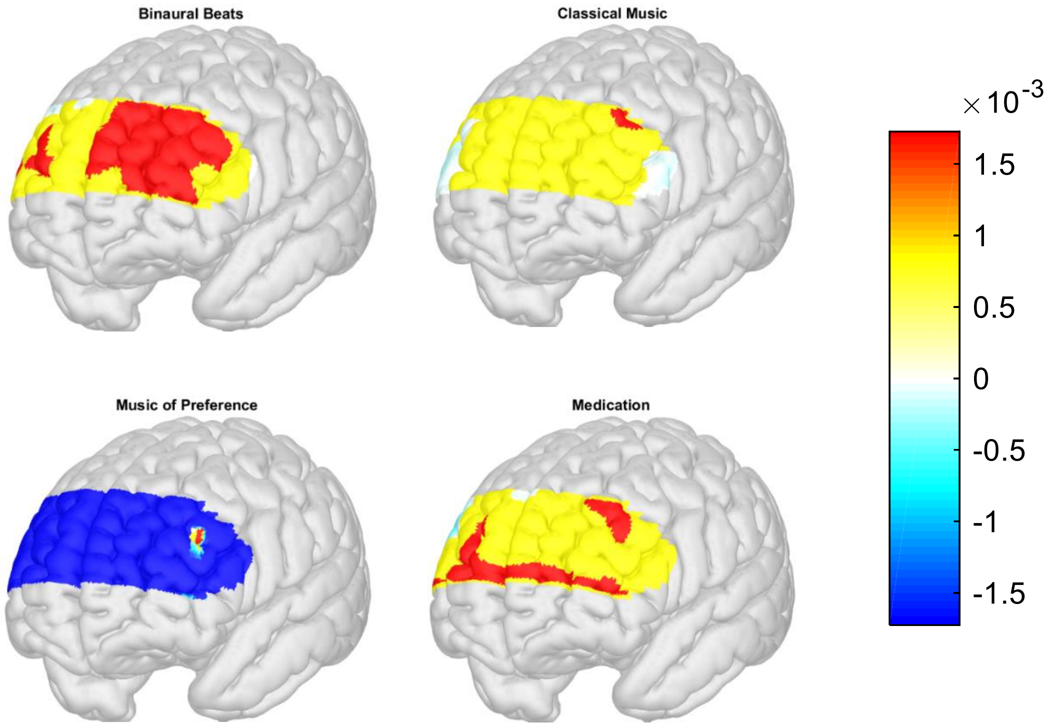


Figure 35: Individual Activation Maps for Sternberg Task

Oxy-haemoglobin activation did not provide any significant results across the sustained attention test although behavioural data indicated a significant difference. Medication differed significantly in comparison to binaural beats with a p-value of 0.003. Dopamine is associated with increased levels of attention as well as motivation; thus, these results are expected as the medication is developed to increase dopamine levels in the brain.

In this test, medication was proven to sustain attention, while binaural beats negatively affected attention. This result is contradicting to the results of Lane *et al.* (1997). Lane *et al.* (1997) found that participants stimulated with beta-frequency binaural beats indicated improvements in target detection during a vigilance task.

This study replicated the binaural beat used in Lane *et al.* (1997) and it consists of 200 Hz in the right ear and a variable beat of 216 Hz – 224 Hz in the left ear. Lane *et al.* (1997) also measured performance as participants responded to detect a number of targets. This study does not agree with the results from Lane *et al.* (1997) and even found that silence (control) resulted in better performance in comparison to binaural beats.

Instead, the results are consistent with the findings of Goodin *et al.* (2012), Crespo *et al.* (2013), and Kennel *et al.* (2010) that binaural beats were not responsible for a significant change in reaction time. Kennel *et al.* (2010) conducted a pilot study to determine whether binaural beats can reduce symptoms of inattention in children with ADHD and found that the results did not indicate significant differences.

The study from Kennel *et al.* (2010) suggested that future studies should monitor participants for extended periods of time. This could be a limitation to the current study as 30-minutes of auditory is a short duration for the auditory experience to have an effect on a participant. However, Lane *et al.* (1997) reported differences in just a 30-minute binaural stimulation period.

Looking at the time perception task data of oxy-haemoglobin for this task, did not indicate a significant difference, while the behavioural data indicated a significant difference. Post hoc comparisons of the main effects revealed that medication in comparison to binaural beats positively influenced time perception.

As mentioned in the literature study, individuals with ADHD perceives time as moving more slowly than their unaffected peers (Meaux & Chelonis, 2003). The results of this study indicate that medication was responsible for resulting in the greatest difference in time perception correction.

In general, it was found that binaural beats negatively affected performance during cognitive tests. The study found that 50% of participants rated the enjoyment of binaural beats as neutral, while the rest of the participants indicated that they did not like it. This result confirms the findings of Huang and Shih (2011), that the more an individual likes or dislikes background music the more likely it is to influence attention.

All the participants indicated that they enjoy music of preference a lot while 90% said they enjoy classical music. Although music of preference is the most enjoyed treatment method, the results indicate that musical enjoyment is not directly related to an improvement in cognition. Classical music was not identified as the most liked treatment method, although results indicate that classical music outperformed music of preference during the Stroop task.

Participants rated their ability to concentrate for all treatment methods and 58% of participants had a neutral feeling for binaural beats. The other treatment tests scored the following: classical music 82%, music of preference 66% and medication 82% for either well or very well. Medication and classical music scored the highest among the treatment conditions. The two conditions indicated by participants were also found to influence concentration in a positive way.

This study did not look as specific regions or channels across the prefrontal cortex. Literature indicated that the right and left dorsolateral areas may be impacted by musical experiences (Bigliassi *et al*., 2015). Although no visual difference was observed when activation heat-maps was compared against one another. Studies suggest that the right prefrontal cortex may be involved in ADHD (Castellanos *et al.*, 1996; Dolu *et al.*, 2019; Weber *et al.*, 2005).

This study had a limitation due to the number of participants. Due to unforeseen circumstances, two participants withdrew from this study. Increasing the number of participants will result more statistically reliable results and may provide new insight into how the ADHD brain interacts with music.

Overall, the results indicate that classical music and medication can be seen as an effective method to increase performance during cognitive tests. Binaural beats, in general, were found to negatively affect performance during cognitive tasks while oxy-haemoglobin differences were only picked up during the working memory task.

Aiming to prove that music can be used as an aid for the management of ADHD presented a challenge. As with any other study, this study has a lot of variables that cannot be controlled. Variables such as patient mood, family background and living conditions all have an effect on the results. The results obtained from this study are not revolutionary in the way that this study cannot say with certainty that music can be used as a treatment method for ADHD. However, these results do provide insight into how the ADHD brain reacts to different musical experiences, medication and behavioural tasks.

6 Recommendations

As with any other study, a few recommendations can always be made. Firstly, this particular study did not look into certain areas of the prefrontal cortex as no differences were observed and individual channels were not analysed. Although previous MRI and fNIRS studies have found that the dorsolateral part may be impacted by music and ADHD (Barkley, 1998; Weber *et al.*, 2005). Investigating certain regions of the prefrontal cortex in future studies may broaden the understanding of how music, as well as medication, affects specific areas in the prefrontal cortex.

It is also difficult to interpret the activation of haemoglobin as greater activation is not always better. An example of such a case can be seen in Figure 35; the heats maps indicated an increase in activation although the individual struggled to keep attention on the task at hand. Brain imaging techniques are useful tools to get insight into how the brain reacts although data should be handled with caution.

As this study involved music, the results cannot just be transferred. Music can have different effects on each individual; it has been known that music familiar to the individual was responsible for greater effects (Huang & Shih, 2011; Schellenberg et al., 2007). The study aimed to recruit participants with various backgrounds and university majors with the aim to find universal results. One would expect similar results when using the same songs with the same characteristics although not guaranteed.

The music selected in this study is based on literature and therefore different variations of the music are not guaranteed to produce similar results. This study has a lot of variables that cannot be controlled. Ideally, it would be advantageous to recruit participants with the same demographic variables as music taste is greatly affected by these variables. The number of males and females participated in the study is not equal and therefore also has an influence on results. The social background of individuals was not evaluated and can influence present outcomes.

The results of this study are limited due to the number of participants. Thus, increasing the number of participants would be advantageous to make sure that the results are statistically reliable. The study was conducted in a repeated-measures design due to the limited availability of participants and therefore could be a limiting factor. A drawback of the present study is that testing required a lot of time from participants. Tests were long and during testing, it was observed that participants got tired although the stimulation time was relatively short.

Another factor that could have a negative influence on the results is that the brain is neuroplastic. Limiting the age group of participants participating in the study to 18-25 years limits the ability of the brain to form new connection and pathways. It has been known that the brains ability to form new connections are reduced with age (Voss *et al*., 2017). Therefore, a younger age group may be responsible for different results.

The short duration (30-minute) of stimulation to different musical experiences can also have an effect on the present outcomes. Ideally, one would like to follow participants for extended periods of time in order to determine the effectiveness of the treatment conditions. The following of participants for extended periods of time was not possible in the study due to time constraints.

One disadvantage of the current neuroimaging device is that it detects changes in blood flow resulting from neuronal firing. Hemodynamic activation is an intrinsically slow process whereby EEG technology has a greater time resolution accuracy. The fNIRS has high levels of light scatter within tissue resulting in a limited penetration depth as well as poor spatial resolution. Investigating another neuroimaging device for similar studies would be recommended.

Playing music at different loudness levels was not evaluated in this study. The study instructed participant to listen to music at a loudness level to which they normally do. The effect of music loudness and the ability to concentrate deserves future research.

It has been theorized that students listen to music while completing difficult academic tasks as a method to reduce anxiety or stress. In this study, the participants' moods were not evaluated. Evaluating participants' moods may provide insight into how well the musical experience is perceived. It is recommended to look at the participants' moods and to determine how different musical experiences and medication may have an effect on the results.

Lastly, the design took place in a dimply lit room and external noises were limited although as the room was not soundproof and external noises could be heard. It is recommended to conduct this experiment in a soundproof room to provide minimal distraction to the participants.

7 Conclusions

It was hypothesized that there would be a difference between the four conditions: binaural beats, music of preference, classical music, and medication on the cognitive ability of ADHD individuals. Contrary to what was expected, near-infrared spectroscopy data did not indicate that a behavioural task was responsible for inducing overall significant haemoglobin activation across the prefrontal cortex. Although post hoc comparisons of the main effects revealed that classical music and medication in comparison to binaural beats resulted in greater haemoglobin activation.

The overall results from the behavioural data indicate no significant difference, except for the sustained attention task. The sustained attention task indicated that medication significantly influences attention in comparison to binaural beats. Although the overall ANOVA was not significant the main effects indicated that during the Stroop task classical music outperformed binaural beats as well as music of preference. The effects during the time perception task indicate that medication positively improves time perception in comparison to binaural beats.

The overall results from this study indicate that binaural beats negatively influence performance in comparison to classical music, music of preference as well as medication. The usefulness of using a new innovative fNIRS system was proven as the results obtained provided insight into how the ADHD brain reacts to different musical experiences as well as medication.

This study aimed at proving that concentration for ADHD can be managed by using musical experiences, however, the results obtained from this study are not revolutionary. It provides initial evidence that different musical experiences affect attention in different ways, thereby supporting its potential use as an alternative management method for ADHD.

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Appendix A Experimental Documentation

A.1 Informed Consent

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STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

You are invited to take part in a study conducted by Jan Vorster and Prof Pieter Fourie, from the Biomedical Engineering Research Group (BERG) at Stellenbosch University. You were approached as a possible participant because you have ADHD, ADD or similar condition and have an active prescription for the following medication: Ritalin, Concerta or similar medication. Please take time to read the information presented here, which will explain the details of the project. Please ask the study staff any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied and clearly understand what the research entails and how you could be involved. Your participation is **entirely voluntary,** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

1. PURPOSE OF THE STUDY

ADHD (Attention Deficit Hyperactivity Disorder) or ADD (Attention Deficit Disorder) is becoming one of the number one conditions diagnosed in children as well as adults. The condition usually requires medication that has its own negative effects on the body as well as on the brain. Treatment of ADHD is also expensive and therefore not accessible to everyone in South Africa.

This study aims to find an adjunct therapy method in the form of music therapy to assist with the management of ADHD/ADD. Your participation is needed in order to determine if a correlation exists between music and concentration. The end goal of this study is to determine whether music can be used as a method to improve concentration.

2. WHAT WILL BE ASKED OF ME?

If you agree to take part in this study, you will be asked to name some of your favourite songs or compositions, as well as to bring along your prescription and medication given to you by your doctor. The music provided by you must be long enough to cover a 30-minute testing period. As a subject of the research, a brain imaging device (NIRSIT) will be placed on your scalp. NIRSIT is similar to a head band and will cover the front part of your head. NIRSIT will be placed on your head for a period of 30 minutes at a time for four successive days, so that your brain activity can be monitored. On the first day this will be done twice, once with your brain normally active, and once an hour after taking your prescribed medication. Day one would require two hours in total of your time. On the following three days, you will be played preselected music as well as music that you have chosen.

Written consent template. REC: Humanities (Stellenbosch University) 2017

At the beginning of each testing period, your brain would be monitored in silence for 30 minutes without medication. During each 30-minute recording period, you will be exposed to different types of cognitive tests. The cognitive tests will be a Stroop test, Sternberg working memory test, sustained attention test as well as a time perception test. The Stroop test is a test where the name of a color is written in a different color. You are required to say the color of a word but not the name of the word. In the Sternberg working memory test, you are required memorize certain letters and recall them after a certain amount of time. This test assesses working memory. The sustained attention test is a test which requires you to press a button the moment a star is displayed on the screen. Lastly, the time perception test requires you to press a button and start counting and after a few seconds press the button again. This test assesses your time perception.

After completing the first 30 minutes a break of 15 minutes would be given. After the break the same thing would happen again except this time you would be listening to music while completing the concentration tests. This test will also be done without medication. This would require a total of 1 hour and 15 minutes of your time for the last three days.

If you are aware of any hearing issues you may have it is your responsibility to inform the investigator in advance so that the sound levels of the music can be adjusted accordingly.

This study will take place at the Biomedical Engineering Research Group offices located in the Mechanical and Mechatronic Engineering Department, Faculty of Engineering, Stellenbosch.

3. POSSIBLE RISKS AND DISCOMFORTS

NIRSIT (brain imaging device) are non-invasive and pose no risk to you. NIRSIT may cause discomfort as is placed on the front part of your scalp. If the earphones are set to loudly, they may damage your hearing, but adequate checks are in place to prevent this. The standard risks associated with your medication are involved, of which the doctor who prescribed it should have informed you.

4. POSSIBLE BENEFITS TO PARTICIPANTS AND/OR TO THE SOCIETY

You may not directly benefit from this research, but if the results are positive, it may provide a nearly costless alternative treatment method for patients with ADHD disorder.

5. PROTECTION OF YOUR INFORMATION, CONFIDENTIALITY AND IDENTITY

Any information you share with me during this study and that could possibly identify you as a participant will be protected. This will be done by keeping no medical records and prescriptions. All information linking you to specific data will be kept anonymous. Data will be stored on a hard drive and only personal affiliated with this project will have access to it. No participants will be mentioned or identified in the final research report as well as in future publication. Data collected during the trial period may be used for a future study keeping in mind that all data will be anonymous.

6. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you agree to take part in this study, you may withdraw at any time without any consequence. You may also refuse to answer any questions you don't want to answer and still remain in the study. The researcher may withdraw you from this study if you do not participate in all four successive days of testing, or if the researcher discovers that the data collected are invalid and not useful.

7. RESEARCHERS' CONTACT INFORMATION

If you have any questions or concerns about this study, please feel free to contact Jan Vorster at 18192041@sun.ac.za or 072 911 9656, and/or the supervisor Prof Pieter Fourie at prfourie@sun.ac.za.

8. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

DECLARATION OF CONSENT BY THE PARTICIPANT

As the participant I confirm that:

- I have read the above information and it is written in a language that I am comfortable with.
- I have had a chance to ask questions and all my questions have been answered.
- All issues related to privacy, and the confidentiality and use of the information I provide, have been explained.

By signing below, I ______________________________agree to take part in this research study, as conducted by Jan Vorster.

_______________________________________ ____________________

Signature of Participant **Date**

DECLARATION BY THE PRINCIPAL INVESTIGATOR

As the **principal investigator,** I hereby declare that the information contained in this document has been thoroughly explained to the participant. I also declare that the participant has been encouraged (and has been given ample time) to ask any questions. In addition I would like to select the following option:

	The conversation with the participant was conducted in a language in which the participant is fluent.
	The conversation with the participant was conducted with the assistance of a translator (who has signed a non-disclosure agreement), and this "Consent Form" is available to the participant in a language in which the participant is fluent.

_______________________________________ ____________________

Signature of Principal Investigator **Date**

Written consent template. REC: Humanities (Stellenbosch University) 2017

A.2 Project Flyer

ADHD or ADD?

We need you!

We are seeking individuals diagnosed with ADHD, ADD, or a similar condition, using prescribed Ritalin, Concerta or similar medication.

We need you to take part in a study, theorising that listening to music can be an equivalent to your medication.

If you are diagnosed with ADHD, ADD, or a similar condition please consider participation in our research.

All that is required of you is to bring along your prescription medication as given to you by your doctor. You will also be asked to name some of your favourite songs or compositions at the test.

The test itself consist of your brain being monitored while you are exposed to different tasks which requires concentration. You will be tested under different conditions such as the effect of your medication, response to silence and lastly, response to music.

Participating in this study may help us understand the way our brains interact with music and if music can be used to treat ADHD/ADD!

If you would like to take part, or have any more queries, please contact:

072 911 9656
18192041@sun.ac.za

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A.3 Music of Preference Selection Form

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Music Selection Form

Test Number: ____________________ **(Investigator only)**

Please list in the table below a selection of **songs and/or musical compositions** that **all** meet the following criteria:

- You have a **strong preference** for the song/musical composition.
- You have listened to the song/musical composition **ten (10) times** or more.
- The combined length of the songs/musical composition selection adds up to more than half an hour (**30 minutes**).
- The song/musical compositions are **easily accessible**.

Please take note that you do not need to fill in the entire list, and not all songs/compositions that you list may necessarily be selected to be played to you.

Please list in the songs in **descending order** of preference (most preferred song first).

Do you listen to music when you are studying? Yes ☐ No ☐

	Artist/Composer	**Title**	**Length (min)**
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

A.4 Participant Feedback

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Post-Completion Survey

Test Number: ____________________ (Investigator only)

Thank you for participating in this research. As a final step, please complete the survey on your enjoyment of the music as well as your ability to concentrate.

Please mark the appropriate block according to the scale with an **X**.

1. How well did you **enjoy** the following types of music?

	Type of Music				
	Did not enjoy at all	Did not enjoy	Neutral	Enjoyed	Enjoyed a lot
	1	**2**	**3**	**4**	**5**
Classical Music					
Personal Selection					
Binaural Beats					

2. How well were you able to **concentrate** during the following tests?

	Ability to Concentrate				
	Not well at all	Not well	Neutral	Well	Very well
	1	**2**	**3**	**4**	**5**
No medication or Music					
Medicated					
Classical Music					
Personal Selection					
Binaural Beats					

3. Any comments or suggestions?

Appendix B Data Analysis

B.1 NIRSIT Data

The figure below indicated the Shapiro-Wilk test to confirm that the data is normally distributed. Data shown in the figure is from oxy-haemoglobin (HbO_2).

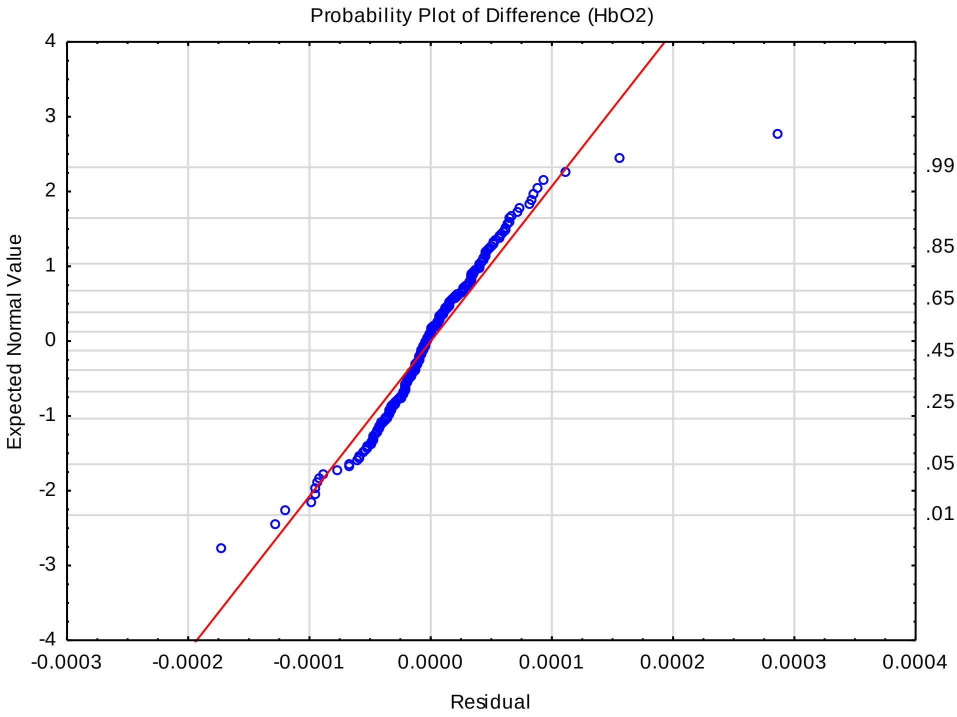
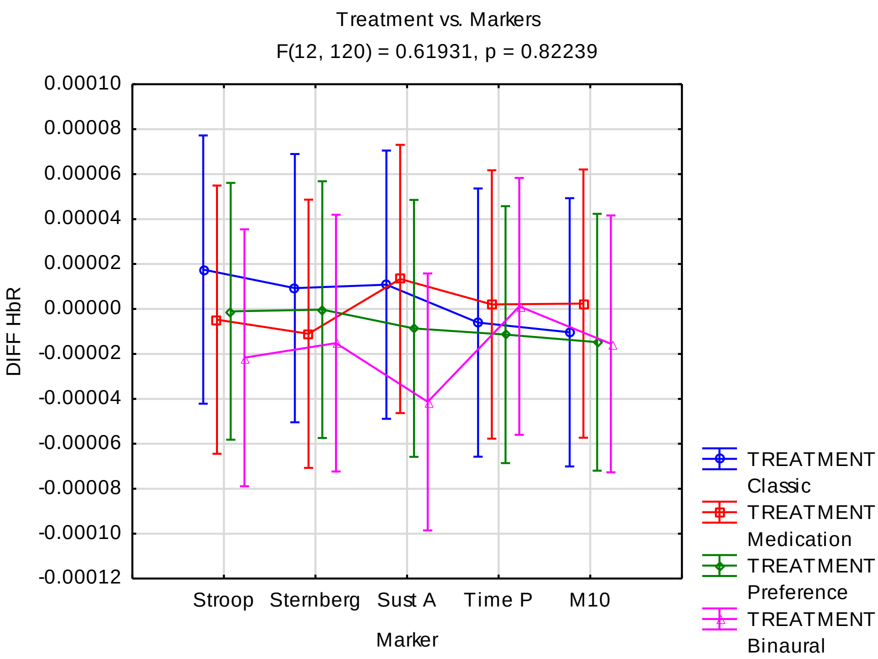


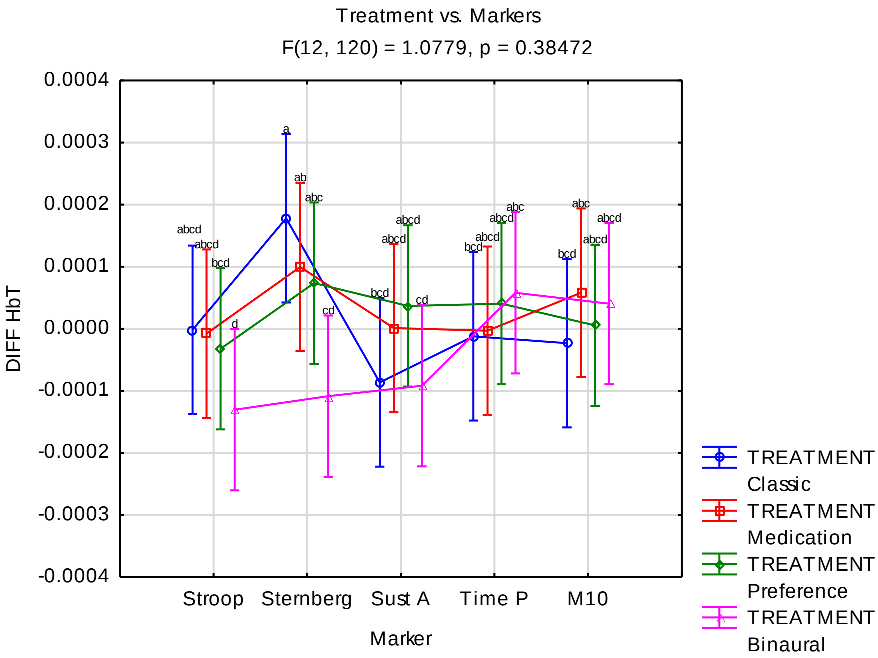
Figure B 1: Probability Plot of Difference (HbO2)

Different treatment test conditions plotted against haemoglobin response can be seen in Figure B 2 and Figure B 3 below. Figure B 2 displays the deoxy-haemoglobin (HbR) response. As seen in the figure an overall p-value of 0.822 was observed. No visual data pattern can be observed therefore results for deoxy-haemoglobin indicate no difference. It is therefore not possible to look at the main effects of data. The total-haemoglobin (HbT) response was plotted in Figure B 3 and the data tend to form a pattern as observed by oxy-haemoglobin (HbO_2) in Chapter 4. Oxy-haemoglobin was chosen to be analysed.



* The vertical bars denote a 95% confidence interval

Figure B 2: Treatment vs. Markers HbR



* The vertical bars denote a 95% confidence interval

Figure B 3: Treatment vs. Markers HbT

B.2 Cognitive Test Data

The mean accuracy difference between control and treatment test as well as the confidence intervals were plotted in Figure B 4 for the Stroop test. No significant differences were observed during this test.

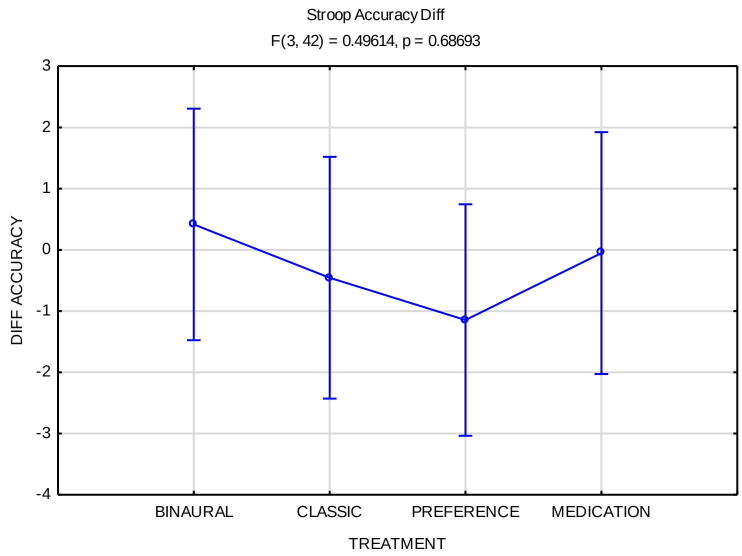


Figure B 4: Stroop Accuracy

The results for the Sternberg memory task can be seen in Figure B 5 below. No significant difference was observed.

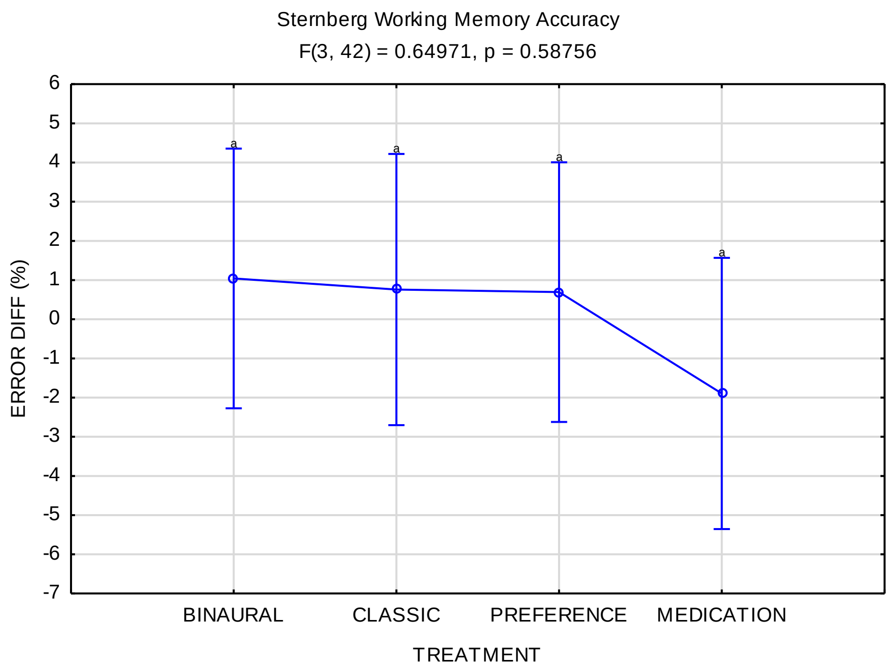


Figure B 5: Sternberg Working Memory Accuracy

Table B 1 is a summary of all the collected results during the time perception test. Individuals were asked to count for 10 seconds. Time perception was influenced by different treatment conditions as seen in the table. The control for each participant on each day as well as the treatment test results is included in the table.

Table B 1: Raw Time Perception Data

Participant	Con B	Binaural	Con C	Classic	Con Pref	Music Pref	Con Med	Med
1	13235.5	12829.5	11984.5	11490.5	13529	10677.5	12464	14636.5
2					18939	19213.5		
3	9548.5	9196.5	11116.5	11456	8275.5	10420.5	10957.5	10779.5
4	12482.2	13241.5	12133	8828	12332.5	10515	12981	11094
5	8390.5	10370	8967	8705.5	7297	11213.5	7451.5	8836
6	12009.5	11947	12693.5	13592.5	10093.5	12359.5	12903.5	11169.5
7	8637	10398	8998	12281	9380.5	10166.5	11440	10066.5
9	11052.5	11825	15693	13108	14588	9734.5	14291.5	12305
10	11173	12173	12523	12103.5	11900	11057	11673	10638.5
11	9239.5	9178.5	8114.5	10003.5	9552	8127.5	12612	7705.5
12	11332	15253.5						
13	9232.5	10707.5	10521	9483.5	11380.5	10195.5	9517.5	9447.5
Average	**10575.5**	**11556.36**	**11274.4**	**11105.2**	**11569.8**	**11243.7**	**11629.2**	**10667.9**

* All the times recorded are in milliseconds. Blanck cells indicate where participants withdrew from the study.

Table B 2 indicates the raw data collected during the sustained attention task. All the reaction times are in milliseconds. The control, as well as the treatment condition for each participant, can be seen in the table. Differences in average reaction time across control as well as treatment condition can be seen in the table. As seen in the table medication was responsible for lowest average reaction time.

Table B 2: Raw Sustained Attention Data

Participant	Con B	Binaural	Con C	Classic	Con Pref	Music Pref	Con Med	Med
1	357.15	347.381	355.03	315.80	362.67	402.58	396.80	261.41
2					337.61	336.87		
3	347.71	378.09	374.46	415.20	357.79	335.25	337.79	382.90
4	297.28	352.11	314.71	352.79	346.39	356.90	347.80	360.74
5	316.70	366.62	368.69	362.62	363.91	364	290.74	306.09
6	250.85	269.95	294.38	280.04	256.77	281.11	299.69	280.38
7	294.34	338	317.57	307.66	351.11	325.31	277.84	306.01
9	330.38	328.39	312.74	317.23	315.92	330.50	316.31	296.06
10	316.04	334.47	351.65	322.63	334.44	333.36	330.22	303.25
11	286.07	299.39	300.63	294.84	312.01	298.73	276.25	269.51
12	346.85	375.06	366.85	350.47	322.71	328.50	369.65	319.43
13	275.20	313.23						
Average	**310.06**	**337.17**	**331.14**	**333.24**	**329.14**	**333.76**	**322.53**	**307.44**

* All the times recorded are in milliseconds. Blanck cells indicate where participants withdrew from the study.

Table B 3 is an example of the mean haemoglobin calculated across the prefrontal cortex for a behavioural task duration. In the table the oxy-haemoglobin, deoxy-haemoglobin as well as total-haemoglobin mean average across all 204 channels can be seen. Channels with a zero indicated that they were rejected. At the bottom of the table the grand mean of all the channels can be seen.

Table B 3: Average Haemoglobin Response Across Marker Example

Channels	HbO2_Average	HbR_Average	HbT_Average
1	0	0	0
2	-0.00059329	0.00024676	-0.00034653
3	0	0	0
4	0	0	0
5	-0.0016838	0.0011598	-0.00052398
6	-0.00014148	-0.00010163	-0.00024311
7	-6.00E-05	-0.00010444	-0.00016446
8	0.00012151	-0.00043318	-0.00031167
9	-0.0034559	0.0035192	6.33E-05
10	0	0	0
11	-0.0017426	0.0020796	0.00033699
12	-0.00014105	7.04E-05	-7.07E-05
13	-0.00061904	-1.98E-05	-0.00063886
14	-0.00016369	4.20E-05	-0.00012173
15	-0.0005146	0.00024264	-0.00027196
16	-0.00028883	0.00026954	-1.93E-05
17	5.91E-05	-0.00010535	-4.62E-05
18	0.00012535	-8.33E-05	4.21E-05
19	0.00010227	-6.69E-05	3.54E-05
20	0.00028661	-0.00017118	0.00011543
21	5.50E-05	2.50E-06	5.75E-05
22	-7.02E-05	8.61E-05	1.59E-05
23	-5.37E-05	-1.61E-05	-6.97E-05

24	3.09E-05	-6.18E-05	-3.09E-05
25	-0.0002682	6.05E-05	-0.00020771
26	-0.00014169	0.00013576	-5.93E-06
27	-0.00018951	0.00012128	-6.82E-05
28	-6.06E-05	7.54E-05	1.47E-05
29	-8.57E-05	0.00038362	0.00029789
30	0.00019738	-3.31E-05	0.00016428
31	0.00057991	0.00041008	0.00098999
32	0.00054994	0.00029008	0.00084001
33	9.73E-05	-2.11E-05	7.62E-05
34	-0.0002294	0.00029744	6.80E-05
35	0.00043631	-0.00046597	-2.97E-05
36	-1.88E-05	-3.37E-05	-5.25E-05
37	-3.70E-05	-3.29E-05	-6.99E-05
38	0.00074224	-0.00087092	-0.00012867
39	-0.000106	0.00014188	3.59E-05
40	0	0	0
41	-0.00016704	1.97E-05	-0.0001473
42	-5.02E-05	3.53E-05	-1.49E-05
43	-0.0001513	6.46E-05	-8.67E-05
44	-0.00054159	0.00049223	-4.94E-05
45	9.23E-05	6.30E-05	0.00015528
46	6.71E-05	0.00014836	0.00021545
47	-9.88E-07	7.45E-05	7.35E-05
48	-6.16E-05	3.23E-05	-2.92E-05
49	0.00024429	-0.00069874	-0.00045446
50	0	0	0
51	-9.52E-05	5.99E-05	-3.53E-05
52	-3.58E-05	-4.81E-05	-8.39E-05
53	-0.00017642	-2.92E-05	-0.0002056
54	0.0010702	-0.00089044	0.00017978
55	-9.57E-05	-5.61E-06	-0.00010129
56	-9.43E-06	-8.82E-05	-9.76E-05
57	-2.22E-05	-3.14E-05	-5.36E-05
58	-3.82E-06	1.42E-05	1.04E-05
59	4.81E-05	6.36E-05	0.00011176
60	-0.0005202	0.00048005	-4.02E-05
61	-3.64E-05	0.00017771	0.00014132
62	-1.20E-05	7.32E-06	-4.67E-06
63	1.17E-06	0.0001085	0.00010966
64	3.15E-05	-5.02E-05	-1.86E-05
65	1.77E-05	-2.18E-05	-4.19E-06
66	-0.00010258	0.00023397	0.00013139
67	0.00027359	-0.00038318	-0.00010959
68	-0.00019511	7.01E-05	-0.00012503
69	0.00013545	-0.000739	-0.00060355
70	0	0	0
71	-0.00070162	0.00029897	-0.00040265
72	4.43E-05	-0.0008318	-0.00078746
73	0	0	0
74	4.42E-05	-0.00017043	-0.00012624
75	0.0027211	-0.0034167	-0.00069563
76	-9.58E-05	6.87E-05	-2.71E-05
77	-0.0033119	0.0044479	0.0011359
78	-0.00044644	-0.00010722	-0.00055365
79	-0.0041572	0.0053078	0.0011505
80	-0.00019686	0.00059495	0.00039809
81	-0.00044694	-0.00055146	-0.00099841
82	-0.0014733	-0.00030537	-0.0017786
83	-0.00068419	0.000827	0.00014281
84	-0.0005122	0.00037031	-0.00014189
85	1.31E-05	2.19E-05	3.50E-05
86	-2.84E-05	0.00010225	7.39E-05

87	4.18E-05	5.85E-07	4.24E-05
88	-5.00E-05	-1.26E-05	-6.26E-05
89	4.57E-05	-6.42E-05	-1.85E-05
90	1.30E-05	-0.00010019	-8.72E-05
91	-0.00023423	0.00011809	-0.00011614
92	-3.33E-05	-9.56E-05	-0.00012888
93	-0.0003525	0.00010593	-0.00024657
94	-2.59E-05	-7.25E-05	-9.84E-05
95	-0.00057846	-0.00013296	-0.00071142
96	-0.00071989	0.00064765	-7.22E-05
97	0.00014905	-0.00017999	-3.09E-05
98	-0.0009985	0.00091058	-8.79E-05
99	-0.00026099	0.00070179	0.0004408
100	0.0010396	0.00037399	0.0014136
101	-3.27E-05	0.00020106	0.00016839
102	0.00017592	-0.00011218	6.37E-05
103	4.80E-05	5.11E-05	9.91E-05
104	-0.00011096	0.00010331	-7.65E-06
105	3.26E-05	-7.68E-05	-4.42E-05
106	0.000562	-0.00056115	8.45E-07
107	9.14E-06	-2.09E-05	-1.17E-05
108	5.60E-06	-1.08E-06	4.52E-06
109	3.78E-05	7.49E-06	4.53E-05
110	-0.00030445	0.00019894	-0.00010551
111	0.00010228	8.90E-05	0.00019123
112	8.90E-05	-0.00010701	-1.80E-05
113	-0.00011859	6.33E-05	-5.53E-05
114	-0.00029368	0.00023417	-5.95E-05
115	-2.24E-06	0.00028541	0.00028317
116	-0.00022301	9.87E-05	-0.00012435
117	-0.00055961	9.89E-05	-0.00046076
118	-0.0025149	0.0016153	-0.00089951
119	-0.00013789	7.03E-05	-6.76E-05
120	-0.00023112	0.00015152	-7.96E-05
121	0	0	0
122	-0.0027033	0.0014305	-0.0012728
123	-0.0030697	0.0029069	-0.00016282
124	-0.00021632	0.00041382	0.0001975
125	8.85E-05	-0.00061434	-0.00052581
126	-9.75E-05	-0.00021482	-0.00031233
127	-0.00064923	0.00017692	-0.00047231
128	0	0	0
129	-3.30E-05	-3.27E-05	-6.57E-05
130	-3.28E-05	-8.41E-05	-0.00011689
131	0.0001567	-0.00027738	-0.00012068
132	-0.00013097	0.00036144	0.00023047
133	6.09E-05	-0.00018149	-0.00012062
134	-0.00044786	0.00020663	-0.00024123
135	-0.0003801	0.00011633	-0.00026378
136	-3.97E-05	-9.69E-05	-0.00013668
137	-4.51E-06	5.39E-05	4.94E-05
138	-1.17E-05	6.63E-06	-5.07E-06
139	-0.00024652	-7.80E-05	-0.00032449
140	0.00039842	-0.00048087	-8.24E-05
141	-3.65E-05	0.0001437	0.00010717
142	-0.00010236	7.65E-05	-2.59E-05
143	0	0	0
144	0.0013233	-0.0013835	-6.02E-05
145	-0.00050055	0.00049014	-1.04E-05
146	-0.00086421	9.84E-05	-0.00076585
147	0.00013076	-0.00016641	-3.56E-05
148	0.00057309	-0.00027806	0.00029502
149	-0.00026613	6.68E-05	-0.00019929
150	-0.00057809	-0.00014219	-0.00072028
151	0.00067724	-0.00049052	0.00018672

152	-0.00010601	0.00017677	7.08E-05
153	-0.00014652	4.27E-05	-0.0001038
154	0.0002401	-3.01E-05	0.00020998
155	0	0	0
156	-0.00015074	0.00018408	3.33E-05
157	0	0	0
158	0	0	0
159	-0.0025849	0.0021338	-0.0004511
160	-0.00046379	0.00052652	6.27E-05
161	0	0	0
162	-0.0001199	-0.00010902	-0.00022892
163	0.00022862	-8.30E-05	0.00014564
164	0	0	0
165	4.69E-05	-3.01E-06	4.39E-05
166	2.66E-05	-6.84E-05	-4.18E-05
167	0.00022885	-0.000275	-4.62E-05
168	-3.85E-05	0.00017993	0.0001414
169	-0.00014258	0.00020998	6.74E-05
170	-0.00016325	-0.00013201	-0.00029526
171	-3.54E-05	-1.79E-05	-5.34E-05
172	-9.38E-05	2.10E-05	-7.29E-05
173	-9.20E-05	8.15E-06	-8.39E-05
174	-0.00012284	2.98E-05	-9.30E-05
175	-0.00027977	0.00017427	-0.0001055
176	-0.00081938	0.00061462	-0.00020476
177	0.00041178	-0.000393	1.88E-05
178	-0.00095848	0.00047449	-0.00048399
179	-0.0013246	0.0012303	-9.43E-05
180	0.00011859	-0.00027864	-0.00016004
181	0.00015881	-0.00013754	2.13E-05
182	-0.00012511	-8.18E-05	-0.00020691
183	0.00011496	-2.15E-05	9.35E-05
184	8.96E-05	-3.79E-05	5.16E-05
185	-4.33E-05	-6.49E-05	-0.00010828
186	-4.87E-05	0.00022227	0.00017356
187	-0.00027279	9.41E-05	-0.00017874
188	-0.00053641	6.71E-05	-0.00046933
189	-0.00044085	0.00020537	-0.00023548
190	-3.23E-05	-4.68E-05	-7.91E-05
191	-7.65E-05	2.24E-05	-5.41E-05
192	0.00017742	-0.00025038	-7.30E-05
193	0.00031349	-0.00030717	6.32E-06
194	2.51E-05	-3.55E-06	2.15E-05
195	0.00017114	-1.24E-06	0.0001699
196	-6.24E-05	6.48E-05	2.35E-06
197	0	0	0
198	0	0	0
199	-0.00011716	-8.40E-05	-0.00020113
200	-7.83E-05	0.00015861	8.03E-05
201	0	0	0
202	-0.00013906	9.98E-05	-3.93E-05
203	0.00010882	-0.00010969	-8.74E-07
204	0	0	0
Average	**-0.000197816**	**0.000129624**	**-6.8192E-05**

Appendix C Music of Preference Selection

The following table indicated the list of music selected by participants. This table is an indication of the board range of music selected.

Table C 1: List of Music Selected by Participants

Artist/Composer	Title
AJR	Sober Up
AJR	Burn the House Down
Alec Benjamin	Jesus in LA
Alexandre Desplat	The Resurrection Stone
Alina Baraz	Floating
Alt J	Every Other Freckle
Amber Run	Fickle game
Amber Run	Insomniac
Amber Run	5 am
Asking Alexandria	Under Denver
Asking Alexandria	Alone in a Room
Asking Alexandria	Room 128
Banners	Got It in You
Banners	Someone to You
Baptize Me	X-ambassadors
Barns Courtney	Fire
Barns Courtney	Golden Dandelions
Beegees	Tokyo Nights
Beyonce	Irreplaceable
Beyoncé	Diva – Homecoming
Billie Eilish	Ocean Eyes
Blink 128	Adam's Song
Brandon Jenner	Death of Me
Brian Adams	This Is where I Belong
Bring Me the Horizon	Mother tongue
Bring Me the Horizon	Nihilist blues
Bullet for my Valentine	Coma
Bullet for my Valentine	Cries in Vain
Bullet for my Valentine	Breath Underwater
Bullet for my Valentine	10 Years Ago
Cage the elephant	Black Madonna
Cage the elephant	Tokyo Smoke
Catfish and the Bottlemen	26
Chance the rapper	Acid rain
Chance the rapper	Cocoa butter kisses
Daughter	Numbers
Dean Lewis	Don't hold me

Dean Lewis	7 minutes
Dean Lewis	Straight back down
Dean Lewis	Half a man
Dean Lewis	Waves
Declan J Donovam	Fallen so young
Delta-Notch	Study Mix: Trace to Study
Dewis Lloyed	Nevermind
Eagle-eye Cherry	Save Tonight
Early B	Bid vir Pouse
Ed Sheeran	What do I know?
Ed Sheeran	Supermarket Flowers
Eluveitie	The call of the Mountains
Eluveitie	The Rose of Epona
Flora Cash	You're somebody else
George Ezra	Paradise
Ghost	Dance Macabre
Ghost	Square Hammer
Grouplove	Welcome to your World
Halsey	Heaven in Hiding
Hans Zimmer	Time
Hans Zimmer	Cornfield Chase
Imagine Dragons	Bad Liar
In Flames	The End
J Cole	Neighbors
Jack Parow	My Koningkryk
James Authur	Falling like the Stars
James Bay	Bad
James TW	Soldier
Jon Bellion	New York Soul – Ft li
Jon Bellion	Good in Me
Jon Bellion	Maby IDK
Jon Bellion	Stupid Deep
Kip Moore	Plead the Fifth
Kyle Landry	Interstellar – First Step
Kyle Landry	Passion
Kyle Landry	Matt's lullaby
Lana del Rey	Ride
Lewis Capaldi	Hollywood
Lewis Capaldi	Grace
Live Forever	Vaportrap – Trip Hop
Lizzo feat Missy Elliot	Tempo
Lord Huron	The Night We Met
Lorde	Team
Lovelytheband	Maby, I'm Afraid
Maroon 5	Cold
Maroon 5	Girls like You
Mickey & Sylvia	Love is Strange
Mika	We are Golden

Mike Posner	I took a Pill in Ibiza
MISSIO	I See You
Passion Pit	Take a Walk
Passion Pit & Galantis	I found you
Pink	Walk me Home
Prime Circle	She always gets what she wants
Queen	These are the Days of Our Lives
Quinn XCII	Tough
Rainbow Kitten Surprise	It’s called: Freefall
Revivalists	It was a Sir
Sabaton	Rorke’s Drift
San Holo	Worthly
San Holo	Surface
Shawn Mendes	There’s Nothing Holding Me Back
Sir Sly	Gold
Sleeping at last	Breath Again
Spoegwolf	Winter
Stereophonics	Indian Summer
Straatligkinders	Goliat
Tash Sultana	Notions
The Hunna	Piece by Piece
The Killers	Glamorous Indie Rock and Roll
The Kooks	Naïve
The Kooks	Bad Habit
The National	Conversation 16
The Neighborhood	Sweater Weather
The Piano Guys	Flickr
Token	Household Name
Token	7th Day
Tom Misch	Move
Tom Odell	Magnetized
Tom Walker	Now you’re Gone
Tom Walker	Leave on a Light
Toto	Africa
Tribe Society	Ego
Trivium	Forsake Not the Dream
Twenty one Pilots	Holding on you
Twenty one Pilots	Jumpsuit
Valiant Swart	Sonvanger
Van Morisson	Brown Eyed Girl