To Yoga or Not to Yoga? The Effect of Yoga on Sustained Attention: An fNIRS Study

By:

Cornelia Cunningham

Student number: 20C6447

Supervised by:

Mr Sizwe Zondo and Dr Victoria Williams

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ABSTRACT

Background: Deficits in sustained attention are ubiquitous across numerous neuropsychological disorders. Besides being critical in learning, memory, and general cognitive capacity, sustained attention is thought to be the primary foundation for 'higher' cognitive functions including, divided, selective, and focused attention. Despite the above, sustained attention remains the lesser-researched form of attention. Sustained attention is thought to be regulated by the default mode network and the central executive network, the latter of which is situated in the dorsolateral prefrontal cortex (DLPFC), a brain region typically associated with sustained attention. Given the contributions of sustained attention in overall cognitive functioning, alternative and natural methods used to enhance this type of executive function are important. One alternative method is yoga exercise, where yoga is thought to place the body into the most favourable state to enhance sustained attention capacity.

Objective: This non-randomised controlled trial investigated the behavioural and neurophysiological effects of yoga practice by comparing a yoga group to a control group, using functional near-infrared spectroscopy (fNIRS). This study aimed to determine whether yoga improves sustained attention performance on the Stroop Colour Word Test (SCWT) in a South African-based sample.

Method: A total of 36 participants (n = 25 females; n = 11 males) were included in this study. The neuroimaging method, fNIRS, was used to measure brain hemodynamic activity, i.e., oxygenated haemoglobin (OxyHb) and deoxygenated haemoglobin (DeoxyHb) in the DLPFC. Participants were given the SCWT, a behavioural measure of sustained attention. More specifically, their results were assessed according to congruent and incongruent reaction time and response accuracy. The fNIRS data were recorded using the CortiPrism neuroimaging Software. Data were then exported to Microsoft Excel, and data analysis was conducted using JASP 0.17.10 and jamovi 2.3.21 statistical software. Statistical analysis consisted of Chi-Square, Independent Samples T-tests analysis, and the Repeated Measures Analysis of Variance (ANOVA).

Results and Conclusion: This study found a significant (p = 0.018) difference between the yoga and control group in incongruent response accuracy scores in the SCWT. However, no statistically significant differences (p < 0.05) were observed in fNIRS individual and group

analyses, SCWT congruent and incongruent reaction time, as well as congruent response accuracy. This suggests that short-term yoga practice may improve behavioural markers for sustained attention, at least in terms of cognitive interference.

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List of Acronyms

BOLD: Blood Oxygen Level Dependent

CEN: Central Executive Network

CFQ: Cognitive Failures Questionnaire

CNS: Central Nervous System

CNX: Vagus Nerve

CPT: Continuous Performance Test

CW: Continuous Wave

DAN: Dorsal Frontoparietal Attention Network

DCS: Diffuse Correlation Spectroscopy

DeoxyHb: Deoxygenated Haemoglobin.

DLPFC: Dorsolateral Prefrontal Cortex

DMN: Default Mode Network

EEG: Electroencephalogram

fNIRS: Functional Near-Infrared Spectroscopy

FOLD: fNIRS Optodes' Location Decider

GLM: General Linear Model

GMV: Grey Matter Volume

Hb: Haemoglobin

HRF: Hemodynamic Response Function

LDPF: Differential Pathlength Factor

mBLL: Modified Beer Lambert law

MMSE: Mini Mental State Examination

MRI: Magnetic Resonance Imaging

MRS: Magnetic Resonance Spectroscopy

NIR: Near-Infrared

NRCT: Non-Randomised Controlled Trial

OxyHb: Oxygenated Haemoglobin.

PFC: Prefrontal Cortex

RAS: Reticular Activating System

RIT: Response Inhibition Task

rCBF: Regional Cerebral Blood Flow

rCBO: Regional Cerebral Blood Ooxygenation

RCT: Randomised Controlled Trial

SCI: Scalp Coupling Index

SCWT: Stroop Colour Word Task

tHb: Total Haemoglobin

TDDR: Temporal Derivative Distribution Repair

ToF: Time Of Flight

List of Definitions

'Bottom-up' attention: This refers to an automatic response to attention that does not require mental manipulation (i.e., frontal, and parietal lobe engagement). Stimuli, such as physical, mental, or environmental stimuli, are thought to automatically 'pop up' into an individual's consciousness.

'Top-down' attention: In contrast to bottom-up attention, this form of attention requires strategic control of brain regions responsible for attention (e.g., frontal, and parietal lobes) to enable human subjects to pay attention to stimuli.

Chromophores: This refers to pigmented compounds directly related to cerebral blood flow. In this manner, a pigmented compound refers to oxygenated haemoglobin, deoxygenated haemoglobin, and cytochrome c-oxidase.

Deoxygenated haemoglobin: This is created after oxygen releases from haemoglobin. Therefore, deoxygenated haemoglobin is not bound to oxygen, thereby lacking oxygen.

Haemoglobin: This refers to the red pigment in red blood cells, consisting of a protein component (a quaternary compound) and an iron complex of a porphyrin. Haemoglobin = globin (protein) + haemochromogen (Fe [II] complex).

Inhibitory control: A key component of executive functioning that allows individuals to inhibit inappropriate thoughts or impulses, and to choose more appropriate behaviour.

Mindfulness: A cognitive state of non-judgemental awareness and paying attention to the present 'moment', which encourages one to pay attention to mental, physical, or environmental stimuli.

Neuroplasticity: The brain's ability to adapt, create, and reorganize connections in the synapses, resulting in alterations in brain structure and function.

Neurovascular coupling: Regulates cerebral blood flow to generate cerebral activity. It also ensures that brain regions receive glucose and oxygen for appropriate functioning.

Oxygenated haemoglobin: Haemoglobin that carries oxygenated blood throughout the body.

Perfusion: It occurs in the capillary network and extracellular spaces of tissue and is described as the volumetric flow rate of liquids per tissue volume. It transports waste products, oxygen, and nutrients.

Photon: A particle of light.

Probe: A sensor that collects information on the amount of light that has been absorbed or dispersed.

Time of Flight (ToF): After light shines into the brain matter, it is thought to create a 'photon banana' bend and travels back from the cortex to the surface of the skin, towards light detectors that absorb the light, also known as time of flight.

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Chapter 1. Introduction

1. Introduction

Yoga is an ancient practice that originated in India ~5000 years ago. The primary objective of this practice is to harmonise both the mind and the body (Basavaraddi, 2015), and to help one reach a mindful state (Taimni, 1961). This type of exercise can be done by anyone, irrespective of religion or culture, as the primary aim is to enhance individual and collective consciousness (Stephens, 2017). Furthermore, the term 'yoga' derives from the Sanskrit word, *yuj*, meaning 'union' (Sarbacker & Kimple, 2015), where this union combines controlled breathing, physical postures, meditation, and mindfulness. To integrate these aspects, yoga practice requires the activation of extensive attentional mechanisms in the brain, which ultimately improves concentration (Taimni, 1961).

In comparison to other types of aerobic exercises, yoga integrates the mind, body, and spirit (DiStasio 2008). It also requires balance, endurance, musculoskeletal strength, and correct postural alignment (Stephens, 2017). Physical postures in yoga are termed 'asanas', where they stretch and strengthen various areas of the body. This rejuvenates the nervous system in developing concentration, and coordination, as well as achieving a tranquil state (Arora & Bhattacharjee, 2008). With regards to tranquillity, yoga stimulates the median forebrain's reward system, resulting in pleasure, while inhibiting brain regions that are implicated in aggression and fear, such as the hypothalamus and the limbic system (Arora & Bhattacharjee, 2008). It has been shown that emotional alterations modify adrenal hormones, as observed with a reduction in urinary cortisol (Arora & Bhattacharjee, 2008).

To date, there are many different styles of yoga (e.g., Ashtanga, Iyengar, and Vinyasa), which all branch from Hatha Yoga. The latter requires physical discipline, particularly strength and flexibility (Amin & Goodman, 2014). Even though these different styles of yoga vary in speed and rhythm, they all require the 'union' of postures, and breathing techniques, which leads to a meditative state and increased mindfulness (Santaella et al., 2019). Iyengar yoga focuses on correct posture alignment by using props and bands (Amin & Goodman, 2014), while Ashtanga yoga entails completing a prescribed series of poses in the same order (Benavides & Caballero, 2009). In contrast, Vinyasa yoga (also known as 'flow yoga' or 'power yoga') incorporates a vigorous flow of movements and requires synchronised breathing (Dybvik & Steinert, 2021).
Furthermore, the various health benefits of yoga extend beyond muscle strength and flexibility, where yoga is on the top ten list of commonly practised alternative exercises, according to a

National Institutes of Health Survey. The study (African Response, 2020) also indicates that there are 90000 yoga instructors and 16% of South Africans have tried yoga before. In addition, 1.1 million South Africans have considered practising yoga in the future. Within the last decade, yoga has infiltrated into Western medicine and is used as an adjunctive type of therapy, where practising yoga to prevent and treat illnesses is defined as 'Medical Yoga' (Stephens, 2017).

1.1 Studies on the Benefits of Yoga

Research indicates that many health benefits arise from yoga practice, ranging from physical, and psychological to cognitive improvements, which might be a result of mindfulness-induced neuroplasticity (Salmon et al., 2009). Based on the current literature, it has been proposed that yoga can assist and slow the progression of cognitive decline associated with neurological disorders, such as multiple sclerosis, Alzheimer's disease, Parkinson's disease, strokes, migraines, Type 2 diabetes, epilepsy, and traumatic brain injury (Acabchuk et al., 2021; Jyotsna et al., 2014; Lundgren et al., 2008; Malhotra et al., 2002; McCaffrey et al., 2014; Naji-Esfahani et al., 2014; Ni et al., 2016; Schmid et al., 2014; Velikonja et al., 2010).

1.1.1 The Benefits of Yoga on Emotional and Psychological Well-Being

Yoga has been associated with improvements in emotional well-being, alleviating impulsivity, reducing social problems, and enhancing the ability to regulate negative emotions in healthy and clinical populations, especially those suffering from HIV/AIDS, depression, anxiety, and attention-deficit/hyperactivity disorder (ADHD) (Arora & Bhattacharjee, 2008; Banerjee et al., 2007; Cerrillo-Urbina et al., 2015; Chiesa & Serretti, 2010; Chou & Huang, 2017; Moadel et al., 2007; Sharma et al., 2006; Streeter et al., 2010).

1.1.2 The Benefits of Yoga on Physical Activity

There has been extensive research regarding the physical benefits of exercise, thus there has been some scepticism as to whether yoga-induced benefits are specific to yoga, or aerobic exercise in general (Erickson et al., 2014). To investigate this further, Streeter et al. (2010) performed a randomised controlled trial (RCT) where they compared a yoga group (n=19) to a metabolically matched walking group (n=15). In this study, they administered mood and anxiety scales and used a magnetic resonance spectroscopy scan (MRS) to measure biometric data. Results indicated that the yoga group experienced a significant decrease in anxiety (p = 0.04), less exhaustion (p = 0.06), increased revitalization (p < 0.001), and tranquillity (p =

0.002) when compared to the walking group ($p = 0.30$), ($p = 0.32$), ($p = 0.04$), and ($p = 0.78$). This suggests that yoga may lead to specific yoga-induced physical and psychological benefits. Ross and Thomas (2010) further contend that yoga's physical and psychological benefits are indeed equal to or greater than other aerobic exercises, as seen in their comparative study. Yoga may therefore result in neuroprotective effects that combat GMV ageing-related decline.

1.1.3 The Benefits of Yoga on Cognition

Regular yoga practice has not only been shown to improve overall mental and physical health but also cognition, including fluid intelligence (Gard et al., 2014b). Although all yoga styles yield similar results, yoga is a physically intense and has been found to substantially increase working memory and visual reaction times (Francis et al., 2019). This improvement is attributed to the effective removal of distractions, continuous activation of neural pathways to release neurotransmitters, and increased sensitivity to the postsynaptic membrane (Francis et al., 2019). Memory is enhanced with regular yoga practice, due to the unrelenting practice of combining breath and physical movement, which plays a role in memory (Srinisha et al., 2018). Continuous weekly yoga practice was found to cause significant changes in mental control, visual, and logical memory in elderly women (Vaezi et al., 2020).

1.1.4 The Benefits of Mindfulness-Based Yoga Practice on Attention

Yoga may also improve overall concentration and attention, as it often incorporates mindfulness techniques. In this context, mindfulness involves inhibiting distracting thoughts, while simultaneously, focusing one's attention on a specific stimulus, thereby, enhancing attentional skills (Froeliger et al., 2012). From a cognitive perspective, short-term mindfulness training has been shown to increase cognitive flexibility (Zeidan et al., 2011) and improve attentional orientation (Jha et al., 2007), which may have a positive effect on sustained attention.

Previous neuroimaging studies have examined the effects of yoga on attention by using magnetic resonance imaging (MRI), electroencephalogram (EEG), and functional near-infrared spectroscopy (fNIRS) (Dev et al., 2019; Dybvik & Steinert, 2021; Froeliger et al., 2012; Malhotra et al., 2021; Sharma et al., 2014). Despite the contributions of these neuroimaging studies, they focused primarily on (1) selective, focused, and divided attention; (2) many used MRI to indicate structural brain differences between yoga and control groups; (3) and the participants engaged in yogic breathing or meditation, which excludes the exercise component of yoga. To the best of my knowledge, this study will be the first in South Africa to examine the neurophysiological effects of yoga practice on sustained attention, using optical neuroimaging techniques. It is envisaged that this study will contribute towards neuropsychological, experimental, and sustained attention research in South Africa. The findings from this study might also assist in improving overall sustained attention in healthy, clinical, and neurological populations.

1.2 Proposed Study

The primary aim of this study was to address the limitations of the above cited studies in the literature. Current fNIRS and yoga studies predominately focuses on: (1) adult males completing selective, focused, and divided attention tasks; (2) studies concentrating on MRI structural brain differences when participants partake in Iyengar or Hatha yoga; (3) population groups of Sub-Continent Indian origin, and (4) yoga techniques focusing on breathing or meditation techniques, as opposed to yoga exercise, which incorporates both controlled breathing and meditation (Goethe et al., 2019). Therefore, my study focused on studying sustained attention, using fNIRS neuroimaging to study functional brain differences between the yoga and control group, it was conducted within a South African population, and concentrated on participants who engage in yogic meditation, with an exercise component. The independent variable for my study was the group of participants (experimental versus control group), while the dependent variables were the fNIRS biometric hemodynamic outcomes and the behavioural outcome from the Stroop Colour Word Task (SCWT).

With reference to the dependent variables, my study was interested in determining whether biometric data could provide insight into the neural correlates and cytoarchitecture associated with yoga exercise and sustained attention. I was particularly interested in understanding whether sustained training in yoga, is associated with increased cerebral blood flow (CBF) as determined by changes in oxygenated haemoglobin (OxyHb); and whether these effects translate to cognition, namely, sustained attention.

The following research hypotheses where are put forward:

(1) fNIRS analysis will indicate that there will be greater activation of OxyHb and decreased deoxygenated haemoglobin (DeoxyHb) at the individual level, within the dorsolateral prefrontal cortex (DLPFC), for the yoga group compared to the control group.

(2) fNIRS analysis will indicate that there will be greater activation of OxyHb and decreased DeoxyHb at the group level, in the DLPFC, for the yoga group compared to the control group.
(3) The yoga group will perform significantly better in reaction time and response accuracy in the SCWT, when compared to the control group.

1.3 Research Structure

The current dissertation consists of six chapters in total. The below paragraphs detail the information contained within each chapter.

1.3.1 Chapter One: Introduction

As previously discussed, Chapter One (this Chapter) details the history of yoga and outlined the psychological, and cognitive benefits of yoga. The Chapter briefly detailed the limitations of previous studies and outlined the aims and hypotheses of the current study.

1.3.2 Chapter Two: Literature Review

The literature review consists of an overview of sustained attention as an aspect of complex control in human cognitive functioning. Neurological and psychological disorders associated with defects in sustained attention are included, as well as the importance of sustained attention in everyday life. The neural correlates of sustained attention, i.e., 'bottom-up' and 'top-down' attentional control associated with yoga, as well as the effects of different yoga poses on cognition, are discussed. Moreover, the literature review highlights published studies investigating the effects of yoga exercise on sustained attention using diverse neuroimaging techniques. The neuroimaging tools commonly used in the selected studies were MRI, EEG, and fNIRS. Due to the dearth of research investigating sustained attention and yoga, the section concludes by stating the limitations of the included studies and how the current study aims to address these limitations through the research objectives and hypotheses.

1.3.3 Chapter Three: Methods

This Chapter details the method used to investigate my research hypotheses. The Chapter specifically details the data collection process, including the inclusion and exclusion criteria employed for research participants. The chapter further details the recruitment and experimental procedures undertaken, the instruments used in the study, and the data analysis procedure that was implemented to test my research hypothesis.

1.3.4 Chapter Four: Results

This Chapter reports on my findings as they relate to the biometric analysis of fNIRS data. The Chapter concludes by analysing behavioural data from the SCWT.

1.3.5 Chapters Five and Six: Discussion and Conclusion

The final chapters highlight and discuss the overall findings of my study, and detail the significance of the research study, its contribution to the literature, limitations, and suggestions for future studies.

Chapter 2. Literature Review

2. Context and Background

Human cognitive functioning consists of six domains, which include: (1) executive functions, (2) social cognition, (3) perceptual-motor abilities, (4) learning and memory, (5) language, and (6) complex attention (American Psychiatric Association [APA], 2013; Harvey, 2022). Executive functions are cognitive functions dedicated to mental flexibility, decision-making, planning, inhibitory responses, and working memory (APA, 2013; Harvey, 2022). Social cognition refers to aspects of cognition involved in considering the thoughts and feelings of others (known as the 'theory of mind') and recognising both positive and negative emotional responses in others (e.g., facial reading, expressive language) (APA, 2013). Perceptual-motor cognition includes mental skills dedicated to gnosis (awareness of colours and faces), praxis (the ability to imitate learned movements), visuo-constructional (hand-eye coordination), perceptual-motor (using perception to create meaningful movement), and visual perception (APA, 2013). Learning and memory are the ability to form long-term, recent, autobiographic, and semantic memory, as well as implicit learning of information (APA, 2013; Kolb & Whishaw, 1998). The language domain allows one to create expressive language (fluency, phonemic, and confrontational naming), receptive language (performing actions after an instruction has been given, and comprehension), as well as the appropriate use of grammar and syntax (APA, 2013). These cognitive constructs are thought to be governed by different types of attention, such as divided, focused, selective, and sustained attention (APA, 2013). My study will focus on sustained attention, which is defined as the ability to maintain attention for a prolonged period without distraction (APA, 2013; Esterman & Rothlein, 2019; Harvey, 2022; Sarter et al., 2001).

2.1 Defining Sustained Attention

Sustained attention, also known as 'vigilance' or 'tonic alertness' (Oken et al., 2006a), is the mental ability to focus one's attention, for an extended period, on tasks that are considered repetitive or monotonous (Esterman & Rothlein, 2019; Unsworth & Robinson, 2020). Not only is sustained attention important for learning and memory, but it also plays a critical role in divided, selective, and focused attention as well as general cognitive capacity (Fortenbaugh et al., 2017; Sarter et al., 2001; Slattery et al., 2022). It also contributes to an important function in everyday life, as it assists with detecting social cues for appropriate communication, driving, academic success, and occupational competence (Isbell et al., 2018; Langan-Fox et al., 2009; Sarter et al., 2001; Schmidt et al., 2009; Yu et al., 2019).

Interestingly, certain factors help one to optimise their cognitive capacity for sustained attention. For example, sustained attention is influenced by motivation, circadian rhythms, arousal, and the vigilance decrement (McAvinue et al., 2015; Thomson et al., 2015; Valdez et al., 2010). The 'vigilance decrement' theory is of particular interest to the current research objectives proposed. The theory suggests that sustained attention decreases as the length of the task increases, and this is a consequence of cognitive 'overload' and 'underload' (Thomson et al., 2015). In this context, the 'overload theory' proposes that paying consistent attention requires mental effort, and thus, continuous performance depletes attentional resources (Esterman et al., 2013; Fortenbaugh et al., 2017). In this instance, the overload theory is evident in sustained attention, as it entails the ability to sustain attention (which requires mental effort) for long periods (which may deplete attentional resources).

2.1.1 Theoretical Models of Sustained Attention

Expanding on earlier theoretical models of sustained attention, such as 'top-down' and 'bottom-up' attention systems (e.g., Bowling et al., 2019; Pinto et al., 2013; Sarter et al., 2001; Swartz et al., 2011), current models of sustained attention reveal that goal-directed attention (e.g., 'top-down' attention) is based on two large-scale brain networks, namely: (1) the default mode network (DMN) and (2) the dorsal frontoparietal attention network (DAN), which is also referred to as the central executive network (CEN) (Bauer et al., 2020; Esterman et al., 2013). There are other models of sustained attention, for example, the opportunity cost, control, arousal, and attentional allocation models (Bauer et al., 2020; Esterman & Rothlein, 2019). However, for this study, the focus was on the DMN and the CEN models, as current neuroscience theories indicate that attention is regulated by an anti-correlation between the DMN and the CEN (Esterman & Rothlein, 2019). Subcortical structures, namely, the reticular activating system (RAS), are thought to arouse the cortex, by enabling the regulation of 'bottom-up' and 'top-down' systems that control sustained attention (Sarter et al., 2001; Swartz et al., 2011; Zillmer et al., 2018). The RAS is thought to 'charge' the DMN and the CEN (Bauer et al., 2020; Bonnelle et al., 2011, Moran et al., 2013).

Neuroimaging studies reveal that the DMN includes the anterior and mediodorsal thalamic nuclei and the basal forebrain. Research further indicates that the DMN has *increased activity during rest* and *mind-wandering*, and it is deactivated during tasks that require purposeful attentional control (Alves et al., 2019; Catani et al., 2002; Catani et al., 2012; Christoff et al., 2009; Esterman et al., 2013). In contrast, the CEN is situated in the DLPFC and is activated during goal-directed and sustained attention tasks (Littow et al., 2015). The CEN is associated with less distractibility, enhanced cognitive flexibility, and improved performance on tasks that require long periods of attentional control (Leber, 2010; O'Connell et al., 2009). The nodes and neural correlates that govern this network system include the bilateral intraparietal sulcus, the bilateral DLPFC, and the bilateral parietal cortices (Bauer et al., 2020; Esterman et al., 2013).

EEG and MRI studies indicate that during cognitive tasks that require sustained attention, the CEN, has an increased level of activation, which decreases activation in the DMN, resulting in an anti-correlational balance between these two networks (Boord et al., 2017; Denkova et al., 2019; Sarter et al., 2001). Simply stated, sustained attention occurs when deactivations within the DMN are amplified, resulting in decreased mind-wandering states, which ultimately, allows the CEN to operate more powerfully in terms of concentration and to achieve fewer lapses in attention (Kelly et al., 2008). The anti-correlation between the two networks regulates the balance of 'top-down' and 'bottom-up' attentional processing in the cortex (Polich 2007; Szuromi et al., 2010). 'Top-down' attentional control stimulates the frontal eye field, intraparietal sulcus, inferior parietal, superior temporal, and superior frontal cortices (Bowling et al., 2019; Corbetta & Shulman, 2002; Sarter et al., 2001). 'Top-down' systems are thus more durable in sustaining attention and require greater mental effort, motivation, and voluntary control, where an example of this system is choosing to actively focus on yoga while being in the presence of distracting stimuli (Swartz et al., 2011). Therefore, this system is thought to take longer to activate (estimated response time: 300 milliseconds), whereas 'bottom-up' processing is activated faster (e.g., 100 – 120 milliseconds) (Ling & Carrasco, 2006; Pinto et al., 2013).

Further to the above, 'bottom-up' attentional systems are theorised to control automatic processes of attention, i.e., that are quickly activated, but rapidly depleted (Bowling et al., 2019; Li et al., 2010). Moreover, 'bottom-up' processing occurs when attention is directed to an external sensory stimulus (e.g., focusing on the distracting stimuli as opposed to one's yoga pose), which activates the ventral frontal and temporoparietal cortices in the lateralised region of the right hemisphere (Bowling et al., 2019; Sarter et al., 2001; Swartz et al., 2011). Even though 'top-down' and 'bottom-up' attention systems are characterised as 'separate and independent', both systems rely on the frontal-parietal networks (Hauck et al., 2015; Pinto et al., 2013; Sarter et al., 2001). The balance of 'top-down' and 'bottom-up' attention is thought to be encouraged by alternative exercises, such as yoga, as yoga practice activates and stimulates neuroplastic changes in attentional processes, thereby, improving sustained attention (Dev et al., 2019; Froeliger et al., 2012; Gard et al., 2014a; Gard et al., 2014b; Schmalzl et al., 2018; Villemure et al., 2015).

2.2 Sustained Attention and Yoga

Yoga intends to harmonise the mind and body to reach a meditative or mindful state (Basavaraddi, 2015; Taimni, 1961). Yoga derives from the Sanskrit word, *yuj*, meaning 'union', therefore, yoga is the union of controlled breathing (pranayama), physical posture (asana), meditation (dhyana), and mindfulness (Froeliger et al., 2012; Sarbacker & Kimple, 2015). It is thought that these aspects of body harmony require the activation of extensive attentional components, where a complete harmony of the body can only occur in the absence of tension, which results in improved concentration (Taimni, 1961). Yoga incorporates *mindfulness* into its practice, i.e., it occurs when one experiences interoceptive and proprioceptive sensations that arise when focusing on respiration and physical poses (Froeliger et al., 2012). Mindfulness is defined as acknowledging and inhibiting distracting emotions and thoughts (e.g., 'mind-wandering'), while simultaneously, focusing one's attention on a specific object or stimuli, and consequently, enhancing attentional processes (Froeliger et al., 2012).

Yoga is thus known to enhance sustained attention, as it increases brain-derived neurotropic factors that are critical for neurogenesis, neuroprotection, neuroplasticity, and the overall functioning of the hippocampus (Cotman et al., 2007; Posner et al., 2015). Moreover, physical exercise releases dopamine, norepinephrine, and serotonin neurotransmitters, which improve executive functions, such as sustained attention (Sarter et al., 2001). According to Slattery et al. (2022), yoga further enhances physiological arousal and cognitive control, thereby targeting sustained attention for goal-directed behaviour, such as performing and maintaining a yoga pose. In the section that follows, aspects related to 'bottom-up' and 'top-down' attention mechanisms are discussed in relation to yoga, 'state training', and sustained attention.

2.2.1 Bottom-Up and Top-Down Attention

Simply stated, yoga places the body in the most favourable state for sustained attention. Research has found that the meditative aspect of yoga targets the 'frontoparietal network' (by maintaining focus despite numerous internal and external distractions), and the 'salience network' (by focusing on meditation, as opposed to other stimuli, thus resulting in a peaceful emotional state), by so doing, activating sustained attention (Hernández et al., 2016; Van Aalst et al., 2020). The frontoparietal network is thought to be responsible for acting as a 'functional hub'. It engages other brain networks by distributing functional connectivity, where these connections are vital for controlling and activating cognitive functioning (Marek & Dosenbach, 2022). In contrast, the salience network is a 'cortical hub', located in the ventral anterior insula and anterior cingulate cortices. This network is associated with subjective salience, such as emotional, cognitive, or homeostatic processes, and plays an important role in switching between the DMN and the CEN (Goulden et al., 2014).

Yoga has been found to direct 'bottom-up' attention by activating cortical and subcortical structures involved in attention. For example, research by Ruhnau and Zaehle (2021) indicates that the vagus nerve (cranial nerve CNX) is activated during yoga, which lowers the heart rate and increases brain activity during attention. Similarly, research by Brown and Gerbarg (2005) indicated that rhythmic, slow breathing during yoga (e.g., 3-5 deep breaths per minute) correlates with increased cognitive control and regulates stress, i.e., due to the activation of the CNX. The CNX is further linked to the anterior cingulate, the angular gyrus (connected to the prefrontal cortex [PFC]) and the DLPFC, which are involved in 'bottom-up' attentional regulation (Aniwattanapong et al., 2022). One type of yoga style that is thought to stimulate CNX is movement-based yoga (Ashtanga and Vinyasa yoga), as the ribcage undergoes active expansions and contractions during certain poses, such as forward and backward bends (Schmalzl et al., 2018). Although slower breathing correlates with CNX activation, Vinyasa yoga usually involves 6-8 breaths per minute, hence, it is faster than breath-focused Hatha yoga. In addition, Vinyasa yoga activates the muscles in the abdomen, which leads to CNX stimulation, as it modulates the gut-brain axis, thereby, improving overall brain activity and attention (Breit et al., 2018).

Furthermore, yoga is involved in 'top-down' attentional processes of sustained attention. MRI studies, for example, reveal that the neural processes in the frontal oculomotor network (e.g., associated with monitoring performance and inhibitory control) are activated during yoga. This activation is thought to allow an individual to sustain attention for a specific yoga pose (Gherri, & Forster, 2014; Riva et al., 2018; Schmalzl et al., 2018). This network is further thought to initiate the visual gaze of focus during bodily balance, which allows an individual to inhibit distracting stimuli. Consequently, the frontal oculomotor network encourages sustained attention during yoga practice (Schmalzl et al., 2018).

In summary, yoga integrates 'bottom-up' and 'top-down' attentional processes, and consequently, it plays an integral role in attentional regulation (Froeliger et al., 2012; Izzetoglu et al., 2020). This further supports the notion that yoga is a 'union' of the mind and the body, as both 'bottom-up' and 'top-down' attentional processes are involved. 'Bottom-up' attentional enhancement is derived and initiated by vagal stimulation (CNX), and physiological procedures related to sensory input, movement, breath, and heart rate control. Similarly, 'top-down' cognitive procedures are initiated by attentional components that derive from mindfulness and meditation. Consequently, yoga integrates both 'top-down' and 'bottom-up' systems, which are further modulated by the DMN and the CEN (the DMN becomes further deactivated so that the CEN can be more active, thus reducing mind wandering and increasing sustained attention) (Denkova et al., 2019; Sarter et al., 2001).

2.3 Neuroplasticity, State Training, and Sustained Attention

Yoga practice has been found to enhance 'neuroplasticity' in the brain, and as such, it is of particular interest to the current study. Neuroplasticity is defined as the brain's ability to modify, alter, and reorganise itself, with the aim of adaption (Cramer et al., 2011; Kolb & Whishaw, 1998). This occurs in response to new experiences which stimulate the brain to form new and prune existing neural connections, to recreate dendrites, synapses, and to encourage axonal sprouting (Kays et al., 2012). Neuroplasticity is thought to be related to neurogenesis and gliogenesis (the formation of new neurons and glial cells), both of which are regulated by negative and positive factors from the environment, which causes neurons in the central nervous system (CNS) to have morphological alterations in both negative and positive neuroplasticity (Lafenetre et al., 2011; Vance et al., 2010; Vance et al., 2012). Positive neuroplasticity, which is of interest to my study, increases the amount of cognitive reserve within the brain, resulting in more robust and convoluted neuronal connections, which improve neuronal communication (Vance et al., 2012). Positive neuroplasticity can be further enhanced by several factors, such as environmental enrichment, physical exercise, meditation, mindfulness, a healthy diet, balanced sleep hygiene, and learning new skills that stimulate the mind (Lafenetre et al., 2010; Mueller et al., 2013; Rossi et al., 2006; Stangl & Thuret, 2009; Tolahunase et al., 2018; Wall et al., 2012; Yu et al., 2021). With learning new skills, humans ought to adhere to the 'use it or lose it' theory. This entails that if a skill is left unused for a while, these underused brain and body systems result in atrophy, where the energy needed to maintain them is transferred to other areas (Vance et al., 2010).

Network training and state training are two approaches related to positive neuroplasticity that have been found to improve sustained attention (Tang & Posner, 2009). In this context, '*network training'* refers to practising a series of cognitively designed tasks to 'train' cerebral networks that are associated with attentional brain regions (Posner et al., 2015; Tang & Posner, 2009). On the other hand, *'state training'* encourages a natural attentional 'brain state' by engaging in alternative practices such as meditation or exposure to nature (Posner et al., 2015). My research is interested in state training, which aims to develop a brain state which influences attention through constant practice, without the use of cognitive tasks, but rather focusing on meditation, mindfulness, and physical exercise, for example (Posner et al., 2015). Since yoga embodies physical exercise, mindfulness, and meditation, it is considered a state training approach to improving cognition. This type of balance (between 'bottom-up' and 'top-down' attention) thus creates an anti-correlation between the DMN and the CEN (*Section 2.2.1*), which are integral in maintaining and improving sustained attention, as well as creating an environment for state training, which will be further discussed below (Esterman et al., 2013; O'Connell et al., 2009).

2.3.1 State Training

Within the scope of *exposure to nature*, state training leads to a modified mind and body state. This improves attentional performance due to the restoration of attentional efficiency and increased systemic glucose, which are thought to be depleted after excessive attentional control (Tang & Posner, 2009). When training for a state of *meditation*, it is hypothesised that state training enhances the ability to focus on the present moment and not the past or future. This effort requires a change in the state of mind, which results in enhanced use and distribution of limited brain sources, thus influencing the executive attention network (Tang & Posner, 2009). Meditation thus improves attention by preventing mind-wandering from occurring (governed by the DMN) and gaining more control over what to pay attention to (Posner et al., 2015). The objective of mindfulness and meditation is to focus on the activity at hand (breathing, physical movement, arising bodily sensations) while reverting attention when the mind wanders. Thus, yoga is thought to target both 'bottom-up' and 'top-down' attentional regulation (Gard et al., 2014b). The subsequent section details the behavioural studies which support the notion of yoga balancing 'bottom-up' and 'top-down' attentional control, thereby, enhancing reaction time and response accuracy in behavioural assessments.

2.4 Behavioural Studies

Nagendra and Ganpat (2013) researched the extent to which a 21-day yoga intervention affects sustained attention. In this study, sixty-six university students (males n=28, females n=38; between 18 and 37 years of age) performed a sustained attention task, i.e., the *Digit Vigilance Test*. For this test, participants were provided with a series of numbers (e.g., 1-9), which were randomly assigned in rows (e.g., 30 digits per row, 50 per sheet), and they were asked to eliminate numbers 6 and 9 as fast and accurately as possible, without missing any of the appropriate targets (Nagendra & Ganpat, 2013). For the task, behavioural measures were represented by 'reaction time' (the length of time that it took participants to respond to stimuli) and 'response accuracy' (the amount of correct and incorrect responses). Results indicated that after the yoga intervention, the group, who completed 21 days of yoga, experienced significant improvements in sustained attention, with response accuracy and reaction times improving by 31.90% ($p < 0.001$) and 11.66% ($p < 0.001$), respectively. The authors hypothesized that the yoga group experienced improvements in sustained attention, which resulted in overall academic improvements (Nagendra & Ganpat, 2013). The authors only administered one sustained attention task, where an additional sustained attention could have been included to determine whether results were reliable and accurate. The researchers used the same sustained attention task for the pre and post-test which would have made participants familiar with the procedure, therefore influencing the post-test results. Individual differences in how participants strategise may have also impacted the results (Gothe et al., 2019).

In another study, Chou and Huang (2017) investigated whether 8 weeks of yoga practice could improve sustained attention in children with ADHD. Participants included fifty children, between 8 and 12 years old, who had been medically diagnosed with ADHD. They were randomly assigned to either the control group (n=25) or the yoga group (n=25). Sustained attention was measured by the *Visual Pursuit Test of the Vienna Test System* and the *Determination Test*. The *Visual Pursuit Test* examines selective and sustained attention. Data obtained from the study revealed that the yoga group, who underwent yoga interventions for 40 minutes, twice a week, for 8 weeks, exhibited a higher level of accuracy on the *Visual Pursuit Test*, post-test ($p = 0.010$), when compared to the pre-test results. Participants also showed significantly faster reaction times in the yoga group, post-test ($p = 0.001$), and overall performed significantly higher on reaction times tasks ($p < 0.001$), when compared to the non-yoga group. Results from the *Determination Test* indicated higher response accuracy ($p = 0.026$) and faster reaction times in the yoga group, post-test ($p = 0.004$) when compared to the non-yoga group. Interestingly, the study revealed that the yoga intervention improved overall selective and sustained attention among children with ADHD (Chou & Huang, 2017). These findings have been further supported by Kiselev (2021), who observed that yoga improved sustained attention in children with attention deficit disorder (ADD). This study is not only flawed due to its non-randomised control design, allowing for no causal inferences to be made, but also because males outnumbered females, thus resulting in the validity to be questioned. Similarly, potential confounding variables, such as time spent watching television and video games, might influence the neurophysiological data obtained from this study. Finally, the authors could not rule out whether the observed effects were because the control group was less scrutinised than the yoga group.

In another study, Schmalzl et al. (2018) compared movement and breath-based yoga in yoga-naïve university students. Specifically, the study investigated whether these types of yoga styles would reduce stress and enhance sustained attention. This study included 40 healthy male and female university students, between the ages of 18 and 35 years old (M = 24.42, SD = 5.7). Participants were then randomly assigned to a breath-focused yoga group (e.g., yoga breathing techniques, no exercise) (n=18), or a movement-focused yoga group (Ashtanga Vinyasa) (n=22). Sustained attention was measured before and after the yoga intervention, using the *Response Inhibition Task* (RIT). Data revealed that both groups improved in response accuracy on the RIT, post-yoga intervention (p = 0.017). Interestingly, perceptual sensitivity was enhanced in the breath-based yoga group, i.e., increased by 0.046, but it decreased by 0.013 in the movement-based yoga group. Significant differences were observed in sustained attention. For example, the breath-yoga group maintained sustained attention scores throughout the pre- and post-measures, whereas the movement-based yoga group had a vigilance decrement (a phenomenon that demonstrates the decline of performance in target-discrimination) at the post-test assessment (p = 0.036) (Parasuraman, 1986). Interestingly, only the breath-based yoga group had improved post-test reaction time scores, suggesting that yoga improves cognitive functioning.

Schmalzl et al. (2018) propose that movement-based yoga styles, such as Vinyasa and Ashtanga, are not suitable for novices, as these complex yoga styles require different cognitive loads that impact attention when compared to simple breathing-based yoga styles. The findings from this study reveal that experienced yogis in movement-based yoga receive attentional and perceptual benefits more than novices who benefited more from breath-based yoga. This may be because experienced yogis have accomplished the ability to synchronise controlled breathing, physical movement, and mindfulness, allowing them to acquire cognitive benefits more efficiently from complex yoga styles. Whereas novices obtained further benefits from breath-based yoga, as these yoga styles are thought to be less cognitively and physically demanding, thus easier for novices to execute. The authors recommend that future studies would benefit from using longer yoga interventions, and to investigate whether there is a relationship between yoga practice, perceived and physical stress (salivary cortisol). This is to determine whether perceived and physical stress impacts attentional performance and if there are improvements in attentional tasks and daily attentional performance. Cortisol levels in the saliva are highly fluctuating and salivary samples should ideally be collected over numerous days. However, due to logistical reasons, all participant salivary samples were collected on a single day pre and post intervention, which may have had an impact on the overall findings. Future research should consider using a different sample from a different environment, as university students may have higher stress levels than other populations, which could influence the results.

Furthermore, Baklouti et al. (2022) investigated the effects of Hatha yoga on cognitive functioning in the elderly. The total sample size consisted of 30 healthy men, between 64 and 65 years old ($M = 64.5$, $SD = 4.06$). This study used a non-randomised controlled trial (NRCT), comparing a non-yoga group (n=15) to a yoga group (e.g., Hatha yoga instructors with at least two years of experience) (n=15). *The French Adaption of the Victoria Stroop Test*, *The Five Word Test*, *Zazzo's Cancellation Task*, and reaction time tests were used to assess selective and sustained attention. The data obtained from this study revealed that there were no statistically significant improvements in sustained attention between groups. However, although the control group exhibited higher reaction times ($p < 0.05$) than the yoga group, the yoga group had fewer errors in the *French Adaption of the Victoria Stroop Test* ($p < 0.001$) when compared to the control group. This study suggests that long-term exposure to yoga results in improvements in response accuracy. This study would have benefited from administering anxiety assessments, as anxiety is linked to decreased ability to pay attention in the Stroop Test, as well as developing measures to test for socialisation, especially in the elderly, as this could have impacted overall cognitive functioning.

2.4.1 Summary

The abovementioned studies focused on the effects of yoga on behavioural measures (e.g., reaction times and response accuracy) on cognitive tests that assess selective and sustained attention. It has been suggested that improvements in behavioural measures, as observed with the yoga groups, when compared to the control groups, are a consequence of improved GMV in brain regions associated with sustained attention, such as the DLPFC (Froeliger et al., 2012). Below, I examine the electrophysiological, structural, and functional underpinnings of yoga practice on sustained attention, as indicated through neuroimaging studies.

2.5 Neuroimaging Studies

It has been suggested that regular yoga practice results in biological changes within the brain, specifically in areas involved in higher-order cognitive processes, as indicated by neuroimaging techniques, such as EEG, MRI, and fNIRS (Lazar et al., 2005). Most of the studies that have investigated the relationship between yoga and attention have focused on Hatha yoga, and to a lesser extent, Iyengar, and Kundalini yoga. Similarly, these studies do not always specify the type of attention that is being researched, and instead, adopt the umbrella term of 'attention'. Nevertheless, as sustained attention is defined as the foundational driver of attention, it is expected to influence other types of attention (Fortenbaugh et al., 2017). Many neuroimaging studies are correlational and observational in nature, which makes it difficult to imply causation, especially without statistically controlling for third variables (Rohrer, 2018). In addition, people with different brain structures might, for reasons unknown, be drawn to practising yoga, thus the group differences that occur in the cross-sectional studies, cannot be attributed exclusively to yoga with confidence (Villemure et al., 2015). Future longitudinal research is needed to determine whether structural brain differences are indeed from yoga practice or from other factors (Villemure et al., 2015). In the section that follows, neuroimaging studies, using EEG, fNIRS, and MRI methods, will be discussed as they relate to yoga and sustained attention.

2.5.1 MRI Studies

MRI is a non-invasive neuroimaging technique that focuses on spatial resolution by providing structural (sMRI) (cerebral anatomy) and functional (fMRI) measures (Giedd et al., 2015). The technique relies on blood oxygen levels dependent (BOLD) signals to study network connectivity and brain activity thus exploring changes in cortical and subcortical brain regions (Fox et al., 2007; Schidlowski et al., 2020; Zhang et al., 2021). Not only does MRI focus on individual brain regions, but it also assesses cortical thickness, which will be discussed further below.

2.5.1.1 Cortical Thickness

Cortical thickness is influenced by different factors, such as biological sex, drug or alcohol use, and exercise, including yoga practice (Avants et al., 2010; Frangou et al., 2022; Jacobus et al., 2016; Sowell et al., 2007). The average human cerebral cortex's thickness is 2.5 mm, but ultimately, ranges from 1 to 4.5 mm. In this instance, larger cortical thickness is often associated with improvements in cognitive functioning (Afonso et al., 2017; Fischl & Dale, 2000; Lazar et al., 2005; Lin et al., 2015). A growing body of literature (e.g., Afonso et al., 2017; Gothe et al., 2019; Grant et al., 2010; Lazar et al., 2005; Lin et al., 2015) suggests that individuals, who practice yoga regularly, exhibit increased cortical thickness, when compared to those who do not practice yoga, meditation, or mindfulness.

A study by Afonso et al. (2017) investigated cortical thickness in 42 healthy elderly females. Participants were assigned to an experimental group, consisting of yogis, who practised Hatha yoga at least twice a week for 8 years (n=21), and a yoga-naive control group (n=21). In comparison to the control group, the yogis had significantly greater cortical thickness (p = 0.015) in regions associated with executive functions and attention, such as the PFC. Nonetheless, no statistically significant differences in behavioural performance were observed between groups with the *Mini-Mental State Examination* (MMNE). The study reveals that yoga practice has the potential to decrease age-related thinning of the frontal cortex, and as such, may improve executive functions such as sustained attention (Lazar et al., 2005). However, this study is flawed as it only used one MRI scan per participant. It also cannot assume a causal relationship between yoga practice and cortical thickness, as no baseline assessment was included in the study.

Similarly, Lin et al. (2015) examined the extent to which yoga is effective in reducing cognitive impairments in females with early psychosis. Groups were randomly assigned to a 12-week-long yoga intervention (representing the 'yoga group') or a control group that did not receive any type of intervention. Results indicated that the yoga group had increased cortical thickness in the postcentral gyrus ($p < 0.01$), as indicated by seed-based functional connectivity analysis. Increased cortical thickness correlated with improved attention on the *Letter Cancelation Test* ($p = 0.01$), when compared to the control group. These findings are further supported by Mitko (et al., 2019), who showed that increased cortical thickness in the frontal, parietal, somatomotor, and visual cortices are directly associated with improvements in sustained attention. The above suggests that, since yoga requires ongoing attention, it leads to changes in the sensory cortical map, leading to cortical neuroplasticity (Merzenich & DeCharms, 1996). Although participants were randomly assigned to their respective groups, the study is not without fault as no pre-test was included to determine whether changes occurred before and after the yoga intervention. Cortical neuroplasticity is directly linked to yoga and is further supported by Lazar et al. (2005) who researched yoga instructors between 40 and 50 years of age. Interestingly, these yoga instructors had the same volume of cortical thickness as 20 to 30-year-olds. This study supports the premise that yoga practice delays age-related thinning of the cortex, which correlates with optimal cognitive functioning.

2.5.1.2 Overall Grey Matter Volume (GMV)

GMV is the outer layer of the brain that surrounds the cerebral cortex. It consists of unmyelinated axons and soma (e.g., 'neuronal cell bodies'), in which signals are transmitted to the grey matter by the white matter to process and transmit information (Mercadante & Tadi, 2022). Froeliger et al. (2012) investigated differences in GMV and neurocognitive functioning between healthy Hatha yoga instructors (n=7) and yoga-naïve controls (n=7). The yoga instructors practised yoga for a minimum of 45 minutes, three to four times a week, for at least 3 years. Participants underwent an MRI scan and completed the *Cognitive Failures Questionnaire* (CFQ) and psychological assessments to examine anxiety and depression. The data obtained from this study revealed that there were no significant differences in depression and anxiety scores, but differences were observed in GMV between groups. For example, the yoga group exhibited increased GMV in the cerebellar, limbic, frontal, temporal, and occipital regions, when compared to the control group. These changes positively correlated with fewer cognitive failures in the yoga group ($M = 5.7$), when compared to the control group ($M = 12.6$), as measured by the CFQ. Results from this study suggest that increased GMV results in improvements in sustained attention in those that practice yoga regularly. However, along with reduced statistical power from the small sample size, brain differences cannot be directly credited to yoga practice or increased mindfulness and neuroplasticity, as longitudinal research should to be conducted to be certain. The above findings are contradicted by Garner et al. (2019) who used MRI to investigate the impact of yoga on GM density in healthy adults. Participants participated in either the yoga group (n=39), a sport control group (n=32), or a passive control group (n=31), for approximately 10 weeks. Results indicated that the selfselected yoga group had a significantly lower GM density at the baseline, when compared to the two control groups. The authors could not rule out any confounding variables regarding gender, height, or sociodemographic that explained these differences. However, based on the correlation between GM, stress, and blood pressure, they suggest that individuals' who are prone to stress, actively engage in yoga practice for relaxation. Although assignment to the three groups was not random, results may give an indication of the underlying neural structure of individuals who practice yoga. Future research should focus on homogenous groups and to assess blood pressure more frequently to yield accurate results (Garner et al., 2019).

2.5.1.3 The cerebellum

The cerebellum is involved in coordinating bodily movements and mental processing, such as attentional shifting (Froeliger et al., 2012; Mannarelli et al., 2019; Zillmer et al., 2008). Froeliger et al. (2012) found that the cerebellum is volumetrically larger in yogis when compared to the control group. This may be due to yoga's mind-body concept, which integrates motor and cognitive functions, i.e., the central role of the cerebellum (Froeliger et al., 2012). The authors concluded that yoga increases GMV in the cerebellum, which is directly related to the ability to sustain attention during yoga practice (Froeliger et al., 2012).

2.5.1.4 The basal ganglia

The basal ganglia is involved in initiating, regulating, and controlling complex movements, and is implicated in attentional responses before a motor action occurs (Zillmer et al., 2008). It is also implicated in sustained attention and yoga practice. Gard et al. (2015) investigated functional connectivity in the basal ganglia-thalamocortical circuit by comparing Kripalu yoga practitioners (n=16), experienced Vipassana meditators (n=16), and controls (n=15), using MRI methods. Results indicated there were no significant differences between yoga practitioners and meditators (p = 0.367), but this might be explained by the overlap in mindfulness and meditation styles in both practices. Nonetheless, the yoga and meditation instructors displayed more efficient basal ganglia cortico-thalamic feedback loops, even during rest, when compared to the control group (Gard et al., 2015). This may be because mindfulness and meditation involve the repeated activation of the basal ganglia cortico-thalamic feedback loops. Additionally, the yoga and meditation group displayed greater degree centrality in the caudate, when compared to controls. The caudate nucleus plays an integral role in cognitive functioning and aging, this suggests an association between cognitive flexibility and yoga and meditation practice, if structural brain differences were not already present in the participants beforehand (Gard et al., 2015). This study has limitations in that the cross-sectional design allows for no direction of causality can be made, participants were middle-aged thus greater brain activity may be attributed to an off-set of age-related decline or meditation, and there was no objective measure to ensure that participants were resting instead of meditating, during the resting state scan.

2.5.1.5 Hippocampus

The hippocampus is located in the temporal lobe and is part of the limbic system. It plays an important role in memory, mood, and motivation (Anand & Dhikav, 2012; Kim et al., 2021). The hippocampus also influences sustained attention, albeit less important. It is also involved in the developmental process of adult neurogenesis, an important aspect of neuroplasticity (Bonfanti et al., 2011). Research indicates that yoga groups outperform control groups in memory assessments, as yoga is thought to stimulate neuroplasticity in the hippocampus (Froeliger et al., 2012; Hölzel et al., 2011). In a study by Villemure et al. (2015), GMV in the left hippocampus was larger in experienced yogis ($p = 0.004$), when compared to yoga-naïve controls. However, the study revealed that GMV and memory skills were dependent on the number of hours practised per week and the years of yoga experience ($p = 0.015$). Villemure et al. (2015) conclude that increased hippocampal volume could translate to enhancements in sustained attention due to the hippocampus receiving neuroprotective effects from yoga practice. However, this study did not consider whether the yoga group preformed other types of exercise, which may have influenced GMV in the hippocampus.

2.5.1.6 Insular Cortex and Cingulate Cortex

The insular cortex forms part of the cerebral cortex and is involved in cognition, somatosensory, and emotional processing (Kurth et al., 2010). In contrast, the posterior cingulate cortex is involved in regulating arousal, and balancing internal and external attention (Buckner et al., 2008; Leech & Sharp, 2014). These two brain regions are associated with sustained attention (Sepede et al., 2014) in terms of error signalling, target detection, and conflict monitoring (Lawrence et al., 2003). Deficits in the insular cortex are often associated with schizophrenia and bipolar disorder, and these individuals often experience low sustained attention scores, when compared to healthy subjects (Sepede et al., 2012; Sepede et al., 2014).

Similar to the hippocampus, the insular cortex is not largely responsible for sustained attention performance. It is however included, as it may impact attention as it is associated with greater pain tolerance. This is due to the insular cortex's connection to the anterior insular, which monitors subjective sensory experiences, due to the integration of homeostatic sensors (Craig & Craig, 2009). Research (e.g., Lutz et al., 2013) indicates that experienced meditators exhibited enhanced activity in the dorsal anterior insular during pain, which was associated with a decreased baseline activity before pain commenced. This suggests that increased insular volume led to higher pain tolerance in meditators and yogis, when compared to controls (Villemure et al., 2015), due to mindfulness-based activities that require openness to pain experience rather than avoiding it (Lutz et al., 2013). Chronic pain is associated with decreased sustained attention performance, due to decreased overall GMV. This may suggest that yogis have improved sustained attention due to increased GMV in the insular, which results in higher pain tolerance when compared to those who suffer from chronic pain (Kang et al., 2019).

2.5.1.7 Prefrontal Cortex (PFC)

The PFC is of particular interest to the proposed study. It is located in the anterior endbrain and plays an integral, if not the most important role in sustained attention (Ott and Nieder, 2019). Due to extensive network connections with other brain regions, such as the hippocampus, it is thought to regulate emotions, behaviour, and sustained attention (Arnsten, 2011; Szczepanski & Knight, 2014). Aerobic exercise, such as yoga, is thought to improve the connectivity between the PFC and the temporal lobe, as it is associated with emotional regulation, and ultimately, enhancements in sustained attention (Ligeza et al., 2021). A study by Hernández et al. (2016) examined the potential long-term effects of Sahaja Yoga Meditation on GMV in the right insular, inferior temporal, ventromedial orbitofrontal, parietal cortices, as well as left insular and ventrolateral prefrontal cortex, using MRI. The authors compared experienced Sahaja Yoga Meditation practitioners (n=23) to controls (n=23) who were matched according to age, sex, and education. Results indicated that the frontal and temporal lobes in the right hemisphere had significantly higher GMV in the experimental group ($p = 0.002$) when compared to the control group. The experimental group exhibited 6.9% greater GMV in the whole brain compared to the control group. The researchers concluded that the neuroplastic changes associated with the frontal and temporal lobes in the experimental group lead to significant improvements in attentional and emotional control. The study did not match groups with regards to exercise other than yoga. This may have influenced the data obtained from this study as both cardiovascular function and physical activity can alter brain structure (Villemure et al., 2015). Moreover, since all participants had a minimum of five years of Sahaja yoga meditation experience, a ceiling effect could have occurred and therefore no causal inferences could be made.

2.5.1.8 The Dorsolateral Prefrontal Cortex (DLPFC)

The DLPFC is a region of the PFC, located in the middle frontal gyrus, and corresponds to the lateral part of the Brodmann areas 49 and 6 (Hertrich et al., 2021; Mylius et al., 2013). This brain region is associated with superior cognitive control and functioning; hence it is part of the 'multiple demand system' in the frontal-parietal network (Duncan, 2010). The DLPFC is involved in cognitive flexibility (task-switching), inhibition, working memory, planning, maintaining fluid intelligence, and sustained attention (Barbey et al., 2013; Bauer et al., 2020; Chen et al., 2020; Kaller et al., 2011; Oldrati et al., 2016; Ravizza & Carter, 2008). It is also sensitive to dopamine and norepinephrine responses, i.e., excess, or deprived concentrations of these neurotransmitters negatively affect its functioning (Arnsten, 2011). The DLPFC plays an integral role in anti-correlated network activity between the DMN and CEN, where sustained attention is initiated and enhanced. In addition, enhancements in DLPFC activity have been associated with yoga practice, which may have a positive effect on sustained attention (Bauer et al., 2020; Deepeshwar et al., 2020; Froeliger et al., 2012; Izzetoglu et al., 2020).

Bauer et al. (2020) investigated whether mindfulness training could preserve resting state anticorrelation between the DMN, the DLPFC, and sustained attention, using MRI. The study included a randomized, controlled trial and pre-and post-test design, which included 31 children in grade 6 ($M = 11.76$, $SD = 0.40$). Participants were randomly assigned to either an 8-week mindfulness training group (experimental group) (n=16), or a coding training group (control group) (n=15) and engaged in a *Sustained Attention to Response Task* (SART), using MRI. Following the mindfulness intervention, results indicated that the mindfulness group showed significantly higher right-DMN anti-correlation in the DLPFC ($p = 0.02$), and significant improvements in sustained attention performance ($p = 0.03$), as measured by the SART. Due to neuroplasticity, results indicated preserved sustained attention at DMN resting state in the experimental group. Moreover, findings indicated that the control group performed significantly worse on the SART ($p = 0.050$) and experienced a significant decline in sustained attention ($p = 0.04$) at the end of the 8-week study (Bauer et al. (2020). It was hypothesized that results indicated the benefit of mindfulness training in enhancing brain regions associated with sustained attention, as well as the preservation of the DMN-DLPFC anticorrelation, due to neuroplasticity (Bauer et al., 2020). In summary, findings from this study suggest that mindfulness training in yoga preserves and enhances the DMN and CEN anti-correlation, which correlates with improved processing speed, executive functions and working memory capacity (Keller et al., 2015; Ng et al., 2016). Even though considered statistically insignificant, the number of male versus female participants varied, which may have influenced cerebral blood flow in the brain.

2.5.2 Electroencephalogram (EEG) Studies

EEG is a neuroimaging technique that is used to examine electroencephalogram signals (e.g., electrical impulses in the brain) during the performance of cognitive tasks (Ko et al., 2017). EEG indicates physiological states i.e., attention, cognition, memory, perceptual, and sensorimotor operations, through EEG frequency bands: delta (1–3HZ), theta (4 -7 HZ), alpha (8 – 14 Hz), beta (15 – 30 Hz), and gamma (30+ Hz) (Ko et al., 2017).

Brain oscillations that are most important in attention include theta, alpha and beta. Theta frequency bands are implicated in sustained attention and working memory, while alpha-band oscillations are associated with selective attention, inhibitory control, information processing, and relaxation. Research shows that controlled breathing and movement, which are associated with yoga, increases tonic alpha power, and leads to improvements in attention (Malhotra et al., 2021; Sharma et al., 2014). In contrast, the beta band is involved in focused attention and mental activity (Helfrich et al., 2018; Hyman et al., 2010; Klimesch, 2012; Krishnakumar et al., 2015). A study by Takahashi et al. (2005) examined the potential neurophysiological changes in males (n=20) during Zen meditation, using EEG methods. In this study, meditation increased slow alpha power (p <0.001) and fast theta power within the frontal lobe (p = 0.031). These neurophysiological responses are associated with improvements in internalised attention, and potentially, enhancements in sustained attention.

2.5.3 Functional Near-Infrared Spectroscopy (fNIRS) Studies

2.5.3.1 PFC

FNIRS are used to measure cerebral hemodynamic activity by monitoring the changes of OxyHb and DeoxyHb in the brain. This neuroimaging method operates by shining near-infrared light (NIR) into underlying brain regions, which is absorbed by chromophores such as haemoglobin. Jiang et al. (2021) used this method to examine the behavioural and neurophysiological effects of yoga meditation on inhibitory control. The study included a yoga mediation group (n=25) and a control group (n=25). The study revealed that after a five-week yoga meditation intervention, for approximately 15 minutes a day, this group performed better on the *Flanker Task* ($p < 0.05$) and exhibited increased OxyHb in the PFC ($p = 0.037$), when compared to the control group. The data obtained from this study reveals that yoga meditation is an appropriate exercise to temporarily promote brain activation in the PFC, which is critical for sustained attention. The fNIRS probes used in this study, only examined the PFC and excluded other significant subcortical areas of the brain. Moreover, this study requires further longitudinal investigation to distinguish whether yoga meditation has a short-term or long-term effect on inhibitory control. Future research ought to research other populations, as well as to study other forms of yoga meditation, to determine whether different styles affect the brain in a contrasting manner (Jiang et al., 2021).

Similarly, Dev et al. (2019) used fNIRS to compare a yoga group to a control group by examining PFC alterations during a sustained attention task. Although results indicated that there were no differences in task performance, the yoga group (n=20) exhibited increased OxyHb ($p = 0.04$) and decreased DeoxyHb concentrations in the left PFC ($p = 0.002$), when compared to the control group (n=20). Consequently, this study reveals that the yoga group had improved regional cerebral OxyHb in the PFC during the sustained attention task. This suggests enhanced attention in the yoga group, due to increased OxyHb cerebral activity (Dev et al., 2019). This study did not include a post-test to determine the total amount of time that OxyHb is enhanced, or whether it is merely a short-term improvement. The research would thus benefit from including a longitudinal research design and to incorporate other neuroimaging techniques, such EEG methodology, to further support the data obtained.

Despite the contributions of these studies, there is limited research on the effects of yoga on sustained attention, using fNIRS methodology. In addition to this, a systematic review by (Gothe et a., 2019) of the state of fNIRS and yoga studies reveals that the nascent literature predominately focuses on (1) adult males completing selective, focused, and divided attention tasks; (2) and studies focusing on MRI structural brain differences when participants partake in Iyengar or Hatha yoga; (3) and largely population groups of Sub-Continental Indian origin, and (4) yoga techniques focusing on breathing or meditation techniques, as opposed to yoga-exercise, which incorporates both controlled breathing and meditation.

The current study thus aims to address some limitations and gaps within the literature. To this end, my research study: (1) was conducted within a South African context, (2) and sought to recruit both male and female participants and, (3) who were engaged in a variety of yoga styles, such as Ashtanga, Hatha, Restorative, and Vinyasa yoga. To the knowledge of the researcher, this is the first study to examine the potential neurophysiological and behavioural effects of these yoga styles on sustained attention, using fNIRS, in the South African context.

2.6 Research Objectives

The current study aims to contribute to the literature by investigating the effects of yoga exercise on sustained attention by focusing on fNIRS measures. Similar to other studies, such as those by Dev et al. (2019) and Jiang et al. (2021), my study adopted a quasi-experimental research design. The dependent variables for this study included behavioural and neuroimaging data obtained from participants completing the SCWT. The independent variables for the study were the group of participants (i.e., the experimental group that took part in yoga versus the control group). In principle, my study sought to answer the below research question:

Does yoga practice result in overall improvements in sustained attention performance, which is mediated by regional cerebral blood flow (rCBF) in the PFC, as indicated by the SCWT in the experimental group, when compared to the control group?

2.7 Research Hypotheses

Alternative hypotheses include:

(1) fNIRS individual analysis will indicate greater activation of OxyHb and decreased DeoxyHb in the DLPFC, as measured by fNIRS neuroimaging, in the yoga group compared to the control group.

(2) fNIRS group analysis will indicate greater activation of OxyHb and decreased DeoxyHb in the DLPFC, as measured by fNIRS neuroimaging, in the yoga group compared to the control group.

(3) The yoga group will perform significantly better in reaction time and response accuracy measures, as indicated by the SCWT, when compared to the control group.

Null hypotheses include:

(1) fNIRS individual analysis will indicate decreased activation of OxyHb and increased DeoxyHb in the DLPFC, as measured by fNIRS neuroimaging, in the yoga group compared to the control group.

(2) fNIRS group analysis will indicate decreased activation of OxyHb and increased DeoxyHb in the DLPFC, as measured by fNIRS neuroimaging, in the yoga group compared to the control group.

(3) No significant effect will be found between the yoga and control group regarding reaction time and response accuracy measures, as indicated by the SCWT.

Chapter 3. Methodology

3. Research Aims and Objectives

This research aimed to investigate whether yoga practice could improve sustained attention in those who practice yoga at least once a week, for 30 – 60 minutes within a period of at least two months, compared to those who do not participate in yoga. These differences were monitored by fNIRS, i.e., measures in the changes in OxyHb and DeoxyHb levels in the DLPFC. In addition to neuroimaging measures, behavioural measures (e.g., reaction time and response accuracy) were examined when participants engaged in the SCWT, which assesses sustained attention. Yoga participant results were compared to controls to determine whether yoga improved hemodynamic cortical activity and sustained attention due to yoga practice, leading to greater cortical neuroplasticity. As opposed to studying the anticorrelation of DMN-CEN connectivity, my study only focused on the role of the CEN in yoga. Moreover, since the CEN is governed by nodes that include the bilateral intraparietal sulcus, the bilateral DLPFC, and the bilateral parietal cortices (Bauer et al., 2020; Esterman et al., 2013), my study only focused on the bilateral DLPFC.

As previously noted, most studies focused on adult males, selective, focused, and divided attention, Iyengar or Hatha yoga, and MRI structural brain differences between yoga and control groups. Moreover, the population of study has been largely limited to sub-Continental Indian populations, who partake in breathing or meditation yoga techniques, as opposed to yoga exercise, which incorporates both controlled breathing and meditation. Given the above limitations, my study investigated the effect of controlled breathing and meditation yoga (i.e., yogic breathing, meditation, and mindfulness) within a South African-based population, using fNIRS neuroimaging.

3.1 Research Design

The current study adopted a quantitative approach and an intact group comparison design. Moreover, this design took the form of an NRCT, where the overall scores between two groups, namely the experimental group and the control group, were compared using behavioural (SCWT) and fNIRS data. Table 1 details the experimental design used in this study, namely the post-test-only design. A post-test-only design entails creating outcome measures (e.g., fNIRS and SCWT) for the research groups and comparing them to each other (Gribbons & Herman, 1996). This design is flawed as the differences between the two groups may have already existed before the research measures were implemented, and therefore it is difficult to determine whether participants were directly influenced by the intervention (e.g., yoga) itself (Gribbons & Herman, 1996). An NRCT, when compared to an RCT, is defined as a type of research design where participants are allocated a specific group, i.e., it is not randomly assigned (Schmidt, 2017). For example, an NRCT compares group differences that exhibit distinct baseline variables (in this case, people who practice yoga versus those who do not), which may impact the outcome of the study (Schmidt, 2017). Allocation is created by the researcher to investigate the extent to which group differences, (i.e., baseline variable (e.g., yoga practice vs no practice) affect the dependent variable (e.g., sustained attention and cortical hemodynamics) (Schmidt, 2017). Due to its nature, the NRCT approach contains pre-analytical biases and differences, when compared to a RCT (Guerrera et al., 2017). RCTs are described as clinical evidence at their finest (Guerrera et al., 2017). This is because the design enables researchers to investigate how effective a specific therapy or treatment is, through randomization, thus negating the influence of confounding variables, in so doing, directly comparing the effects of the experimental group receiving the intervention (Sørensen et al., 2006). Nonetheless, RCTs are expensive and time-consuming to set up, as the groups need to be matched according to variables, such as age, lifestyle, level of education, and sample size, to obtain reliable and comparable results (Schmidt, 2017; Sørensen et al., 2006).

Table 1

Experimental Research Design

Groups	**Baseline Assessment (Pretest)**	**Intervention Yoga**	**Posttest Assessment**	**Intervention**	**Follow-Up Assessment**
Experimental group	_	X_1	O_1 fNIRS & SCWT	–	–
Passive Control group	–	–	O_1 fNIRS & SCWT	–	–

Note: The above table details the post-test-only experimental design. X is the intervention (yoga practice in which only the experimental group took part in) and O describes the observation as seen via fNIRS biometric data as well as SCWT results.

3.2 Participants

Purposive sampling was used to recruit thirty-six participants (control group, n=18; experimental group, n=18), between the ages of 18 and 53 years. The sample size was based on similar fNIRS studies investigating the effects of meditation (Deepeshwar et al., 2015; Izzetoglu et al., 2020; Jiang et al., 2021), and to a lesser extent, yoga (Dev et al., 2019; Dybvik & Steinert, 2021), on attention and neuroimaging outcomes. Most participants were aged between 18 and 25 years (n=20), followed by age 46 and 53 years (n=9), 32 – 39 years (n=5), and lastly ages 25 – 32 (n=2). For the most part, the researcher attended weekly yoga classes at *Move Makhanda* and *Natural Affinity*[1] two local yoga studios and informed potential participants about the research. The remaining yoga and control participants were sourced using convenience sampling through research posters advertised on campus, in various departments in the university, and on social media (Appendix A). Other modes of advertisement included creating a PowerPoint presentation (Appendix B) shown at the beginning of an undergraduate lecture.

Participants in the experimental group consisted of 15 females and 3 males, with a mean age of 33.18 years. On average, members in the experimental group (yoga) had a minimum of 6 to 12 hours of yoga experience and practised yoga for an average of one to two hours, per week over the last two months. The amount of time dedicated to yoga in the experimental group (e.g., 8 weeks of yoga practice) was similar to that reported in other studies investigating brain structural changes due to yoga exercise (Ajjimaporn et al., 2018; Jiang et al., 2021; Novaes et al., 2020). Participants in the control group consisted of 10 females and 8 males, with a mean age of 31.06 years. The control group did not partake in any yogic exercise. The inclusion criteria were participants 18 years and older, with no reported history of neurological, cognitive, or psychiatric impairments. To further assist in the inclusion and exclusion criteria, as well as to prevent confounding variables, questions pertaining to medication (for ADHD, anxiety, and depression), were included in the Demographic Questionnaire (Appendix C).

3.3 Experimental Paradigm

Best practices for fNIRS research as developed by Yücel et al. (2021) were followed in the execution and implementation of my study. The procedures were followed to enhance

[1] Both yoga studios were based in Makhanda (Grahamstown), and offered different yoga classes, inclusive of Ashtanga, Hatha, Restorative, and Vinyasa yoga.

reliability and to improve the study's repeatability and traceability. In terms of neuroimaging research, an experimental design is a temporary arrangement of stimuli (e.g., SCWT) aimed at recording and evoking brain activation and haemodynamic responses within the brain to answer a specific research question (Yücel et al., 2021). My study design included the administration of the SCWT whilst participants were fitted with an fNIRS neuroimaging device. Each stimulation of the fNIRS and SCWT was repeated twice, to prevent any physiological confounding factors that may influence the signal of the fNIRS recording (Yücel et al., 2021). Experimental designs, using fNIRS methodology, typically, employ either: (1) event-related designs, or (2) block average designs (Izzetoglu et al., 2020). As detailed below, my study employed the block average paradigm to assess hemodynamic differences between the yoga group and the control group.

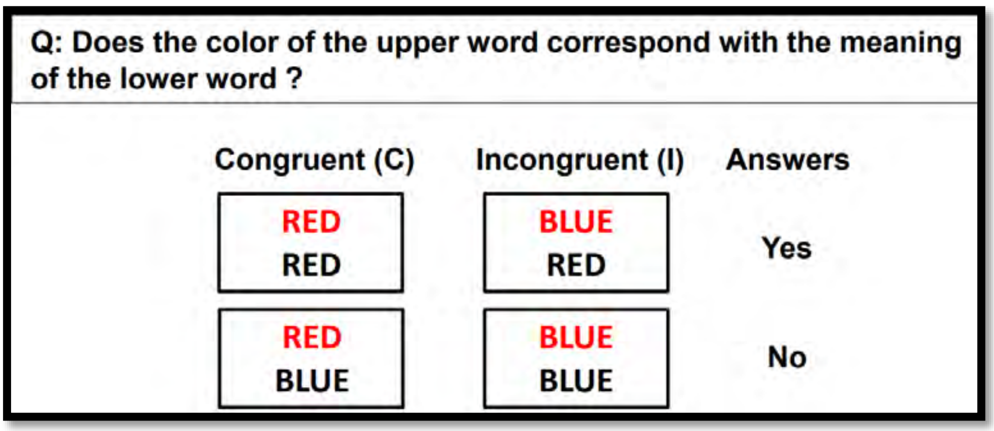
3.3.1 Block Average Design

The hemodynamic response (blood oxygenation level dependency) is assumed to take a linear progression. This is to say that a stimulus that is briefly presented, causes neural activation which stimulates the hemodynamic response (arising from oxygen and localised blood flow) (Kim et al., 2022; Luke et al., 2021). This gives an indication of the regions involved with neurovascular coupling, where when the stimulus is removed, block designs allow the hemodynamic response to return to a baseline level (Kim et al., 2022; Luke et al., 2021). In its implementation, the block average design used in neuroimaging research often consists of a series of blocks of neuronal activity interspaced with blocks of 'rest', indicating no, or limited neuronal activity. Typically, task-related blocks (> = 10 seconds), evoke the hemodynamic response, which is indicated by an increase in OxyHb and a decrease in DeoxyHb. Significantly, the increase in OxyHb is associated with rCBF, with is in turn associated with the brain's need for oxygen and glucose to meet the neuronal and metabolic demands of a cognitive task associated with the active block. The rest period is indicated by limited neuronal activity. Due to the above assumption (neuronal activity, interspaced by rest period), evoked hemodynamic responses, are always juxtaposed by baseline levels of rest (Luke et al., 2021). This alternative between rest and evoked potential is thought to achieve optimal neurovascular coupling, also known as the blood oxygen level-dependent (BOLD) (Luke et al., 2021), leading to the block design evoking greater hemodynamic responses compared to the event-related design (Wald & Polimeni, 2015).

For my study, the block design approach consisted of a sequence of blocks that included congruent and incongruent stimuli lasting 10 seconds, interspaced with rest periods of 15 seconds where participants were required to stare at a fixation cross. These time periods are thought to evoke the hemodynamic response and to achieve optimal neurovascular coupling (Izzetoglu et al., 2020; Luke et al., 2021; Wald & Polimeni, 2015). In total, the neuroimaging for the SCWT block design took a total of 7 minutes to complete. Since two runs were conducted for each participant, the overall SCWT neuroimaging task took 14 minutes in total. During the completion of the SCWT, fNIRS biometric data was collected, using a continuous wave (CW) paradigm. The block design paradigm implemented in my study was adapted from the early work of Schroeter et al. (2002), who employed an event-related design to investigate neurovascular coupling using the Stroop Test. For my analysis, as indicated in Figure 1, the overarching question that participants were required to answer was: '*Does the colour ink of the top word match the meaning of the bottom word*?'. This paradigm is a slight deviation from the original Stroop Test and was tested multiple times throughout a 10-second block design. The SCWT included two conditions: Condition one was a *Congruent* Block (this is where the colour word presented in the top row was the same as the one at the bottom). Condition two was an *Incongruent* Block (the colour word presented is a different colour). As indicated in Figure 1, in the incongruent example the colour of the top word (blue) does not correspond with the meaning of the bottom word. In total, each block (Congruent vs Incongruent) was presented 5 times, for a total of 10 trials, as indicated in Figure 2.

Figure 1

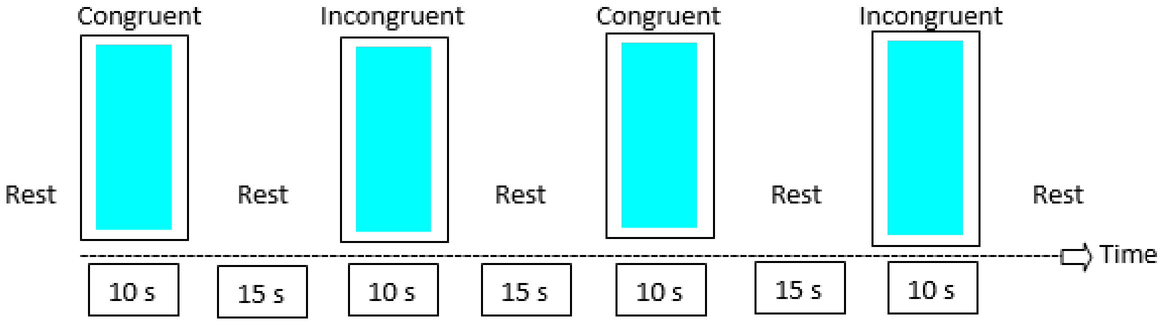
Congruent and Incongruent Stimuli



Note: The above figure displays how congruent and incongruent stimuli were represented. This image was captured by Schroeter et al. (2002).

Figure 2

A Sketch of the Block Paradigm



Note: The above sketch illustrates the block average paradigm. Block one was a set of congruent stimuli where participants were required to press '*q*' on the keyboard. This was followed by a 15-second rest period. Thereafter, the second block was initiated, consisting of incongruent stimuli, where participants were required to press '*p*'.

3.4 Instruments

3.4.1 Demographic Questionnaire

The *Demographic Questionnaire* (Appendix C) was included in this study to determine whether the control and experimental groups were homogenous in terms of age, weight, educational background, and diet. Participants completed the Demographic Questionnaire online, using the REDCap software (Harris, 2019). REDCap is a web-based software platform that is considered safe and secure for data capture purposes in current research. Participants took 10 minutes to complete the questionnaire, at a time convenient for them.

3.4.2 Stroop Colour Word Task

As mentioned, the SCWT was used to collect behavioural and fNIRS data on sustained attention. The SCWT is a neuropsychological test widely used in clinical and experimental research to assess behavioural performance on sustained and selective attention. Traditionally, the assessment is timed, and responses are based on response accuracy and reaction time. The psychometric properties of the SCWT are well-documented and include high test-retest reliability (0.67, 0.78, 0.80 and 0.88, for participants between 18 to 49 years; and *r* =0.64 -0.84, for participants older than 50 years) (Savas et al., 2020). The internal consistency of the SCWT has been reported as moderate to high (*r* = 0.86), where 23 - 42% of the total variance is accounted for by age and level of education (Savas et al., 2020). The assessment is traditionally involved in targeting the frontal lobes and assessing the inhibition of automatic responses, such as word reading, in favour of another response, i.e., identifying the colour of the word of a written automatic response (MacLeod, 1991; Vendrell et al., 1995). In its application, the SCWT requires participants to name the colour of the ink, rather than reading the word (Scarpina & Tagini, 2017).

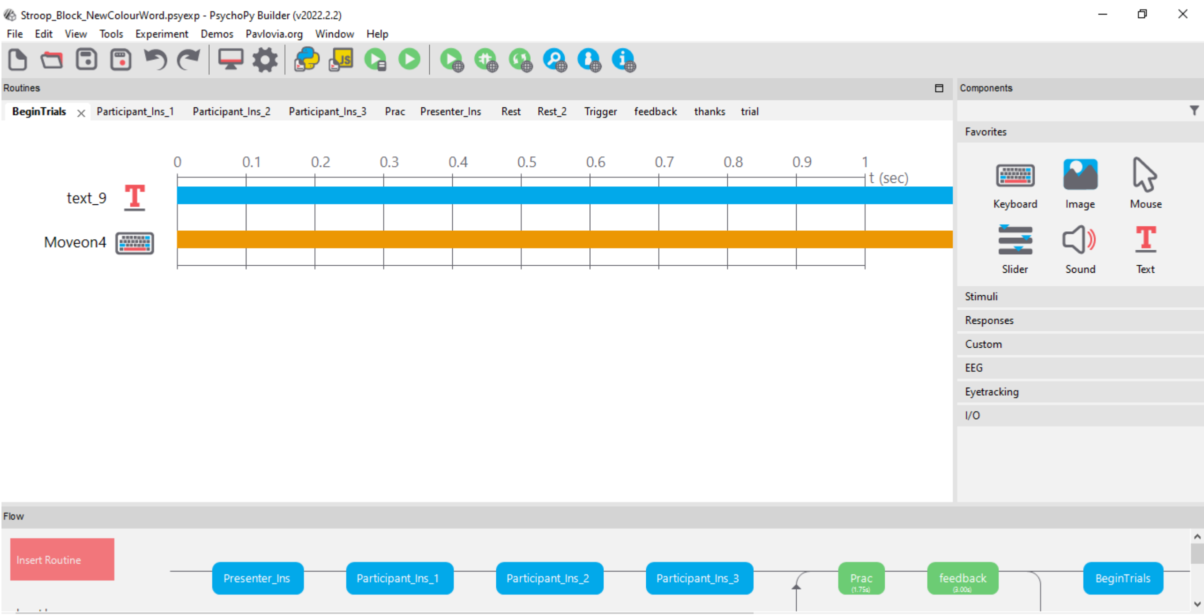
In the slightly modified SCWT, used in my study (based on Schroeter et al., 2002), participants are asked if the colour that the word is written in matches the word written at the bottom of the screen. For example, Congruent stimuli is when the word and colour match, i.e., when the word 'blue' is written in blue ink. In contrast, *Incongruent* stimuli is when the word and colour *do not* match, i.e., when the word 'blue' is written in red ink (Izzetgolu et al., 2020). In the computerised version used in my study, participants pressed the letter '*q*' on the computer keyboard for 'congruent stimuli' and '*p*' for 'incongruent stimuli'.

In terms of behavioural significance, the SCWT, according to Vendrell et al. (1995), targets human nature's vulnerability to interference. Cognitive interference occurs when incongruent stimuli (when the word and ink colour do not match) lead to slower reaction times due to the incongruent relationship between the two constructs (Vendrell et al., 1995). This phenomenon is referred to as the 'interference effect' or 'Stroop effect' and occurs when conflict arises between the (1) automatic word-reading response (irrelevant stimuli) and the (2) non-automatic colour-naming response (relevant stimuli) (Ludwig et al., 2010). Research indicates that participants are prone to choosing the natural response, as opposed to inhibiting their initial automatic responses. Given the interference effect, responses to incongruent stimuli tend to have slower reaction times, leading to a markedly slower response when compared to reacting to congruent stimuli (Grandjean et al., 2012; Stroop, 1935). Participants are thought to better resolve the interference effect by either enhancing the inhibition of the irrelevant response or by increasing their attention on the relevant colour-naming response (MacLeod & Sheehan, 2003).

For the current study, the SCWT was programmed, using PsychoPy 2022.1.2 (Peirce et al., 2019). Figure 3 illustrates the typical PsychoPy GUI used to create the SCWT. Participants were required to avoid 'non-target' stimuli and to respond to the 'target' stimuli. Responding to non-target stimuli is known as commission errors, which measure impulsivity, while the absence of responding to the target, is classified as an omission error, which measures inattention (Slobodin et al., 2020). Based on this paradigm, the SCWT examines cognitive flexibility, as well as selective and sustained attention (Kane & Engle, 2003; Jensen & Rohwer, 1966).

Figure 3

SCWT on PsychoPy



Note: The above figure illustrates the creation of the SCWT on the PsychoPy 2022.1.2 software (Peirce et al., 2019).

3.4.2.1 Neural Correlates of the SCWT

The DLPFC is typically associated with sustained attention and is activated in the SCWT during conflict resolution (e.g., an individual needs to override the automatic response for a more appropriate response in a top-down attentional processing manner) (Egner & Hirsch, 2005). Moreover, the DLPFC is also typically activated when incongruent stimuli follow a pattern of predictable congruent stimuli (Aarts & Roelofs, 2011). Even though the SCWT is traditionally associated with selective attention and inhibitory responses, it has also been used to measure sustained attention in fNIRS studies (e.g., Izzetoglu et al., 2020). Given the above, the SCWT has deemed an appropriate measure of sustained attention for the current research objectives, using fNIRS.

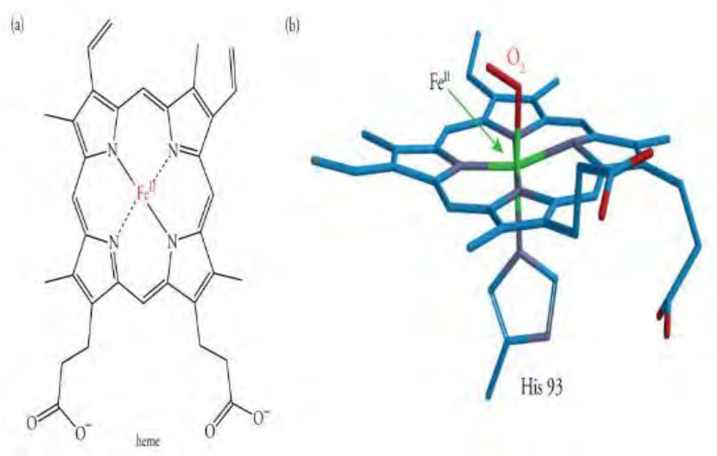
3.4.3 Basic Principles of Functional Near-infrared Spectroscopy (fNIRS) Neuroimaging

In comparison to other neuroimaging techniques, such as diffusion tensor imaging (DTI), positron emission tomography (PET), magnetoencephalography (MEG), MRI, and single-photon emission computed tomography (SPECT), fNIRS is considered a safe, affordable, portable device (e.g., used in research settings and real-life situations), easy-to-use, and a non-invasive neuroimaging technique. In comparison to MRI, fNIRS has a higher temporal resolution and permits lengthy measurements due to its tolerance to participant movement. Moreover, the technique has been found to achieve appropriate estimations of hemodynamic responses in the brain (Quaresima & Ferrari, 2019).

The fNIRS neuroimaging technique is a useful technique for measuring changes in OxyHb, DeoxyHb, and total haemoglobin (tHb) levels, by placing optical sensors on the surface of participants' heads. In this manner, haemoglobin is embedded as the main chromophore (located in the capillaries as well as in the venular and the arteriolar bed) that absorbs NIR light (Quaresima et al., 2012). Haemoglobin is considered to have a quaternary protein structure and is found in red blood cells that carry and transport oxygen throughout the body. Instead of a tertiary protein structure, it is made up of two pairs of different proteins, where each of the four proteins binds oxygen to a Fe (II) ion in the centre of a heme molecule (Ouellette & Rawn, 2015). Due to quaternary protein structures being arranged in protein chains or subunits, connected by van der Waals forces and hydrogen bonds, photons in the form of infrared light, can absorb heme, thus indicating the oxygenation of blood in the cortex (Ouellette & Rawn, 2015). Figure 4 represents an image of a quaternary protein structure.

Figure 4

Haemoglobin Quaternary Structure



Note: Figure 4 illustrates the quaternary structure of haemoglobin. (a) Lines of the bond structure. (b) Heme oxygen complex. Research indicates that during any form of cognitive activity, oxygen is sent by blood perfusion into the capillaries by neurons, to generate energy for cerebral activity. Heme is thus absorbed by NIR light, giving an indication of blood oxygenation (León-Carrión, & León-Domínguez, 2012). This image was captured by Ouellette and Rawn (2015).

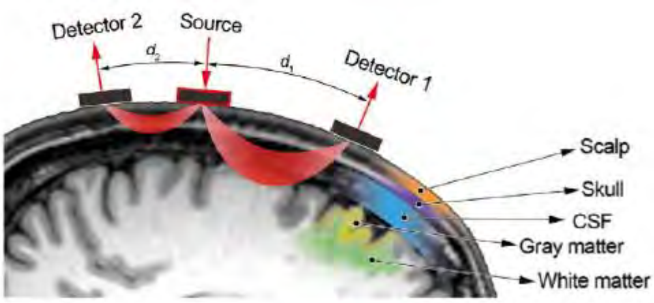
The *functional* aspect of fNIRS neuroimaging indicates that fNIRS relies on neurovascular coupling, also known as the BOLD response, whereas fNIRS provides a functional contrast between (1) functional changes in regional blood flow and (2) an indication of areas containing cerebral activation (Karim et al., 2012). For instance, when a cognitive task is initiated, such as paying attention for a prolonged period (associated with sustained attention), there is an increase in OxyHb transported to the cortical region, namely the DLPFC, which leads to a reduction of DeoxyHb in the DLPFC. Thus, in that sense, fNIRS is 'functional' and not 'structural'. Unlike MRI, fNIRS does not create structural images which can be analysed to make sense of how brain regions function, but it rather indicates where cerebral regions function (Yücel et al., 2017). S*pectrometry* is the study of analysing certain materials by measuring the reactions of wavelengths and the intensity of the scale of radiation, and the interactions between light and matter (ATA Scientific Instruments, 2020).

In its practical sense, spectrometry is linked to shining NIR light which absorbs haemoglobin (Jagdeo et al., 2012). NIR light is emitted at two wavelength ranges, namely, 760 and 850 nanometres (nm), which is considered 'invisible light', to infrared light (Jagdeo et al., 2012). NIR light, therefore, shines into the human cortex and is subject to various factors, where a small fragment is absorbed by the skull and the brain, including cerebral spinal fluid, grey, and white matter (Jagdeo et al., 2013). However, most of the light is absorbed by light-absorbing pigmented molecules (called chromophores), including OxyHb, DeoxyHb, and cytochrome c-oxidase, where haemoglobin is the primary chromophore that absorbs the NIR light (LeónCarrión, & León-Domínguez, 2012; Pinti et al., 2020).

fNIRS thus measures OxyHb, DeoxyHb, and tHb at a functional level within the cortex. Sources that emit NIR light and detectors that capture the NIR light are therefore able to measure any changes in cerebral haemoglobin due to neuronal and metabolic demands of nerve cells within the cerebral cortex (Yücel et al., 2017). After light shines into the brain matter, it is thought to create a 'photon banana' bend and travels back from the cortex to the surface of the skin, towards light detectors that absorb the light, this is also known as time of flight (ToF) (Pinti et al., 2020). The greater the distance between the light source and the detector, the lower the intensity of captured NIR light (León-Carrión, & León-Domínguez, 2012). In a typical study, a source-detector distance of 4 - 5 cm for an adult's head is sufficient for NIR light penetration, although this depends on age, location on the scalp, and NIR light intensity (Quaresima et al., 2012). However, for this study, the source-detector distance was set between 2.5 and 3 cm, as fNIRS spatial resolution is limited to this optical distance (Tak et al., 2016), where a distance less than 20 mm is less sensitive regarding grey matter hemodynamic levels when compared to 30 mm (Yamada et al., 2012). Figure 5 below illustrates the NIR light procedure (photon banana bend) and its application. The increased amount of light that is absorbed in specific brain regions, indicates the regions involved during task performance (Pinti et al., 2020). Importantly, an increase in OxyHb, due to an increase in metabolic demand (active Blocks), results in a decrease in DeoxyHb (León-Carrión, & León Domínguez, 2012), as indicated in Figure 6.

Figure 5

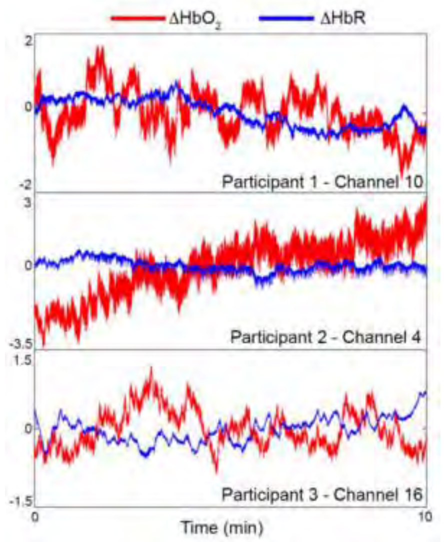
NIR Light Procedure



Note: Figure 5 was captured by Pinti et al. (2020) and illustrates the interaction of chromophores, with light. Here, the procedure is as follows: (1) Light shines from the light source emitter; (2) light travels into the brain matter, makes a photon banana bend and (3) Light finally travels back to the surface of the skin, to where the photodetector is placed (León-Carrión, & León-Domínguez, 2012; Pinti et al., 2020).

Figure 6

Hemodynamic fluctuations



Note: This image was taken from Pinti et al. (2019) and illustrates changes and an increase in HbO (oxygenated haemoglobin) and a decrease in HbR (deoxygenated haemoglobin) on three different fNIRS channels (10, 4, and 16) from three distinct participants.

3.5 Experimental Procedure

Data collection was conducted over 20 days, from 12 August to 1 September 2022. The researcher visited two yoga studios, *Natural Affinity* and *Move Makhanda*, three to four times a week, for 20 days, to recruit participants. Research posters were also created and circulated for recruitment purposes. Once ethical clearance was obtained for this study (RU-HREC: 2022-5505-6841) (Appendix D), four phases of data collection were conducted. In phase one, an email, detailing the nature of the research, was distributed to university students at Rhodes University (Appendix E). This email was accompanied by two research posters that were advertised on campus and at yoga studios, detailing the nature of the research for recruitment purposes (Appendix A). In addition, a PowerPoint presentation about the research was created and presented at the beginning of a psychology undergraduate lecture (Appendix B).

Phase two of the study included interested participants contacting the researcher, either via email and/or WhatsApp to receive more details about participating in the study. Phase three included the researcher emailing all necessary documents to participants, including the participant information sheet (Appendix F), fNIRS information sheet (Appendix G), consent form (Appendix H), and demographic questionnaire (Appendix C). All participant data were automatically captured online using the Research Electronic Data Capture (REDCap) software (Harris, 2019). Once data was captured, the researcher screened all the participant data to ensure the inclusion and exclusion criteria were met. Once participants met the inclusion criteria, a Zoom meeting was scheduled for the researcher to answer any questions about the research and to build rapport with participants. Phase four entailed participants reading and signing the written informed consent form, as well as further detailing the nature of the study, confidentiality, anonymity, risks, and the right to withdraw from the study at any time.

The experiment took place in a secure experimental room in the Psychology Department at Rhodes University. Upon arrival, participants first followed Covid-19 safety protocols to reduce the potential spread of the virus. The participants were asked to sanitize their hands and to be screened for Covid-19 (Appendix I). Participants were then asked to complete their personal details (e.g., name, contact number, and date of attendance), for contact tracing purposes. The experimenter and participant were also asked to wear masks to limit any potential exposure to any airborne participles. Before and after the experiments, the stationery and fNIRS equipment were disinfected with 70% alcohol. In addition to this, the windows were opened, and distance was maintained between the researcher and the participant (e.g., 1.5 meters) whilst they completed all protocols related to the study.

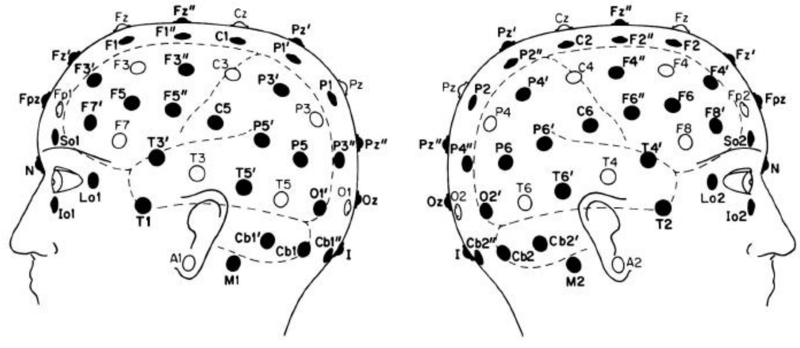
Once all the above health and safety protocols were followed the researcher and participant sat opposite each other, established rapport for 10–15 minutes, and started a research checklist (Appendix J). Rapport consisted of welcoming the participant into the research room, and engaging in conversation regarding yoga, university, careers, and whether participants had previously engaged as a research participant in any other study. Once the checklist was completed, the experiment was explained to the participant (Appendix K). First, the SCWT was explained to the participants, and then they were asked to engage in a 2-minute practice run to familiarize themselves with the task at hand. Thereafter, participants were asked to sit in front of the laptop. Whilst sitting at the laptop, the researcher explained how the fNIRS neuroimaging device functions, i.e., the fNIRS measures the amount of OxyHb and DeoxyHb present in the brain. Subsequently, the instructions of the computerised SCWT were described. Once the process was clearly explained and all questions answered, the experimenter measured key fiducial points, namely the participant's head circumference, the distance from the inion (bump at the back of the head, above the neck) to the nasion (decline between the forehead and nose) (Faul, 2007). Once the above points were established, the fNIRS cap was fitted onto the participants based on the standard 10 – 20 system (Trans Cranial Technologies, 2012) (*Detailed in 3.5.1*). Room lights were then switched off to prevent external light from impacting the optodes of the fNIRS cap. Once the optodes and fNIRS cap were tightly fitted, imaging signal quality (indicated via a green or orange light) was established; neuroimaging recording and SCWT experiment commenced. Participants performed the SCWT task twice and data collection lasted approximately 45 minutes per participant.

3.5.1 Research Protocol

In the experimental room, the participants were seated in a comfortable chair, with a laptop (e.g., screen diameter: 19 centimetres; height: 34.6 centimetres) positioned directly in front of them, and details of the study were clearly explained to them (refer to Appendix K for more on this). Regarding the neuroimaging protocol, the fNIRS cap was further fitted with a black overlayer cap to prevent any external light from affecting the probe signals. Cap and probe placement (e.g., sources and detectors) were placed according to the international 10-20 system. This system divides the placement of electrodes into 10% intervals across the entire surface of the scalp. The '20' refers to electrodes being 20% of the total right-left or front-back distance of the human skull (Trans Cranial Technologies, 2012). Below, Figures 7 and 8 provide a visual representation of the 10-20 system that was used in the study.

Figure 7

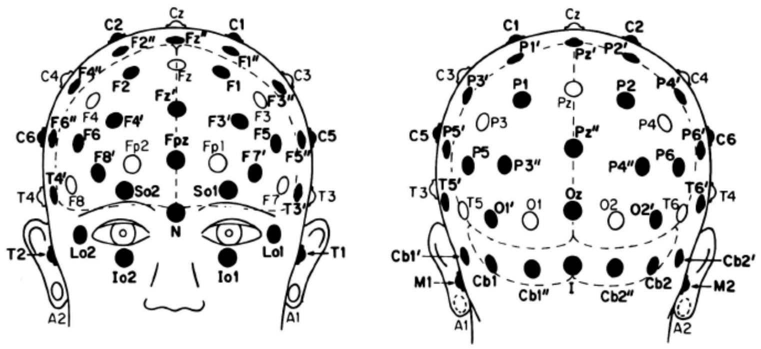
Lateral view of the 10/20 system for electrode placement



Note: Auxiliary leads (placed above underlying brain regions) are in black, and the 10% system is in white. Electrodes on the left (represent the odd numbers) and right side of the brain (as indicated by the even numbers) represent the cortical and sub-cortical areas examined (Chatrian et al., 1985). Electrodes F3, F1, Fp1, Fp3 (left image), Fz (middle), and F2, F4, and Fp2 (right image) are placed over the DLPFC.

Figure 8

Anterior and Posterior view of the 10/20 electrode system for electrode placement



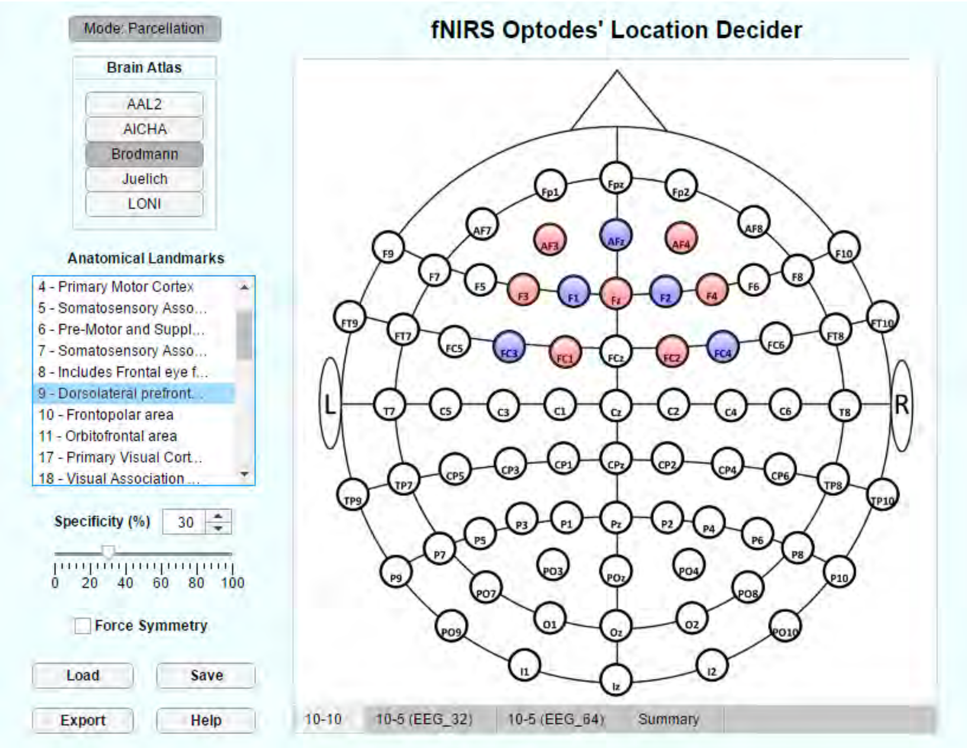
Note: The auxiliary leads are represented in 'black' and the 10% system are in 'white' (Chatrian et al., 1985). Posterior cortical regions are marked as double prime (") and anterior regions are marked as prime ('). Study optodes were placed on the DLPFC (electrodes F3, F1, Fz, F4, Fp3, Fp1, and Fp2)

Probe placement (the placement of paired sources and detectors) was positioned at a maximum distance of 3 cm. The placement of the optodes on the fNIRS cap was based on published literature measuring sustained attention in the DLPFC (Bauer et al., 2020; Sarter et al., 2001). Similar to other studies (e.g., Dev et al. 2019; Izzetoglu et al., 2020; Jiang et al., 2021), probes were positioned bilaterally over the PFC (using the 10-20 system), with a particular interest in the DLPFC.

To assist with the probe placement of the DLPFC, the fNIRS Optodes' Location Decider (FOLD) was used (Zimeo Morais et al., 2018). Based on FOLD, coordinates, sources that emitted the fNIRS light, (shown in 'red') were placed on regions AFz, F1, F2, FC3, and FC4. Detectors, used to capture the fNIRS light (as indicated in 'blue') were placed on regions AF3, AF4, F3, Fz, F4, FC1, and FC2. The above probes were located, using Brodmann parcellations for the DLPFC. Below, Figure 9 details the source and detector placement.

Figure 9

The fNIRS Optodes Location Decider (FOLD)

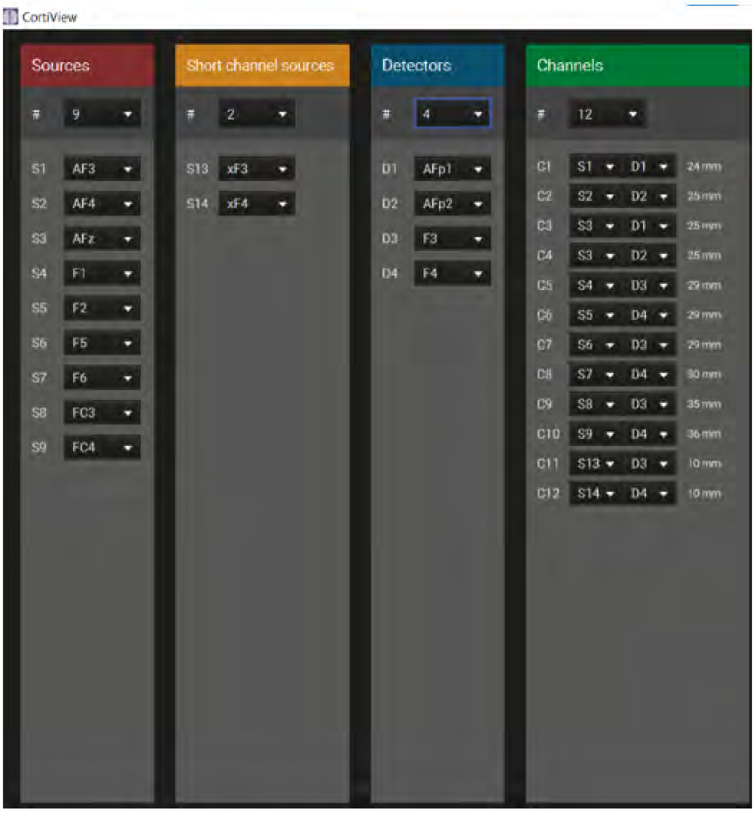


Note: DLPFC regions for the placement of probes, were configured using the FOLD application. Parcellations were based on Brodmann's brain atlas.

To ensure cross-talk between software, FOLD coordinates were transferred to the Cortiview Software, an fNIRS data recording software from Cortivision, 2022. Lab Streaming Layer (SLS) integration within Cortiview, was further designed on PsychoPy to send triggers related to the SCWT. Figures 10 and 11 below indicate the final probe placement, using the Cortiview software.

Figure 10

Cortiview Montage



Note: The montage displays the settings for the fNIRS device. Each column indicates the sources, detectors, and channel locations and their numbers. The first column displays the nine sources, followed by two short channel sources in the second column, and the four detectors in column three. The study had a total of 12 channels as indicated in the last column.

Figure 11

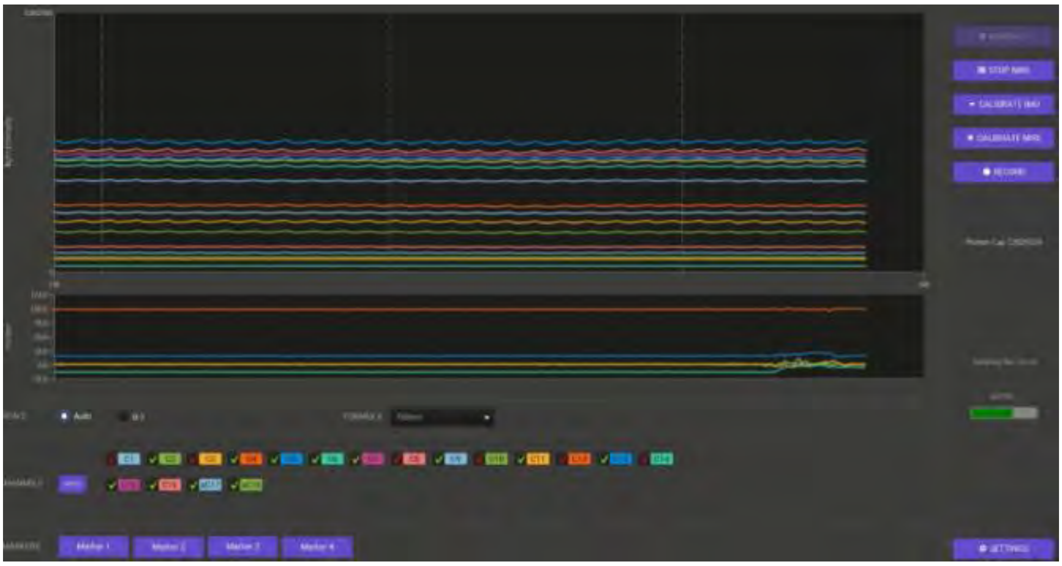
Optode Arrangement

Note: Nine sources (S1-S9, as indicated in red), four detectors (01-04, as indicated in blue), and two short separation channels (S13 – S14), were recorded for 12 channels (C1 – C12) using Cortiview Software

Once participants were fitted with the fNIRS cap, they completed the SCWT, as described in *Section 3.4.2*. The rCBF for each hemisphere was updated every five seconds at a sampling rate of 7 – 8 Hz. Once the recording was complete, the behavioural and fNIRS data obtained from the study were automatically transferred to an Excel file for data analysis. When the experiment was complete, the fNIRS cap was carefully removed from the participant's scalp, and participants were thanked for their participation. The removal of the fNIRS cap was immediately followed by disinfecting the cap with 20% ethanol. Fibre optical probes (e.g., sources and detector) were wiped with paper tissue diluted with isopropyl alcohol at a 70% concentration. Pens and table surfaces were also disinfected with 70% alcohol-based sanitiser. The fNIRS decontamination procedures are further detailed in Appendix L. Figure 11 below captures an example of real-time fNIRS biometric recording.

Figure 12

Real-Time fNIRS Recording



Note: The above figure, illustrates the live recording of fNIRS signals. The colours represent raw brain waves that were converted to optical density measures. This image was captured from Cortivision (2023).

3.6 Data Pre-Processing Before Data Analysis[2]

3.6.1 fNIRS Pre-processing Steps

Neuroimaging data (e.g., fNIRS, EEG, etc) inherently contains ‘noise’ from different sources, namely, physiological, and instrumental noise. Physiological noise includes respiration, blood pressure, heartbeat, Myer waves, and changes in blood carbon dioxide concentration (Nguyen et al., 2018; Pinti et al., 2019). Instrumental noise, on the other hand, refers to noise from the surrounding environment (e.g., external light), or hardware (e.g., instrumental instability or degradation). To remove noise, and to pre-process raw neuroimaging data for analysis, several pre-processing steps were undertaken, as detailed below.

Firstly, each fNIRS recording was saved to a Shared Near Infrared Spectroscopy Format (snirf) file and loaded to CortiPrism Data Analysis Software (Figure 13). Raw imaging data was first trimmed 10 seconds before the SCWT recording, and 10 seconds after the SCWT was completed. Data trimming was followed by ‘signal quality checks’, i.e., green (high signal quality), orange (medium signal quality), or red (low signal quality) signals, as shown in Figure 13. Signal quality (green, orange, red signal) processing was based on the Scalp Coupling index

[2] As per recommendations from Yucel at al., 2018, data preprocessing procedures are detailed in the Methodology Chapter, and not the Results section.

(SCI). The SCI refers to measuring the amount of blood moving in the scalp. This is also known as a measure of photoplethysmography cardiac signal, which helps to determine the channels that contain adequate and inadequate levels of signal quality and blood reaching the optodes (Pollonini et al., 2016; Sappia et al., 2021).

Figure 13

Pre-Processing Tab

Note: The pre-processing of fNIRS data followed suggestions from Cortivision (2023).

Following signal check, raw data was converted to optical data, to assess the quality of the signals more easily and to inspect heartbeat oscillations and the presence of large motion artefacts (Pinti et al., 2019). As indicated in Figure 13, this *pre-processing* step was followed by Temporal Derivative Distribution Repair (TDDR). The TDDR is a type of motion correction which is based on robust regression that does not require any external parameters (Fishburn et al., 2019). In its application, this motion correction filters and discards spike artefacts and baseline shifts arising from head movements as well as excessive head movements typically found in children, the elderly, and those with ADHD, autism spectrum disorder, and epilepsy (Fishburn et al., 2019; Yerys et al., 2009). Please see Appendix M for an example of signal quality for three yoga and three control participants at different channels of interest.

TDDR motion correction was followed by Butterworth filtering. Butterworth filtering is considered a model-based bandpass filter which is used to reduce frequency signal strength, that occurs due to cardiac pulsations and instrumental noise (Khan et al., 2020; Yücel et al, 2021). To remove cardiac pulsations and instrumental noise, Butterworth high pass (HP) and low pass (LP) filtering were applied at a standardized value of 0 - 0.2 Hz. High pass filtering thus removed frequency components within the signal above the frequency cut-off (0.2Hz) and low pass filtering removed signal frequency components below the frequency cut-off (0 Hz) (Pinti et al., 2019).

Once the above steps were undertaken, Short Channel Corrections were applied to the data. Specific to optical neuroimaging, short channels are applied to control for signals emanating from the scalp and not the brain. Short channels are thus used to remove superficial confounding signals, to remove physiological noise caused by the fNIRS optodes (detectors and sources) (Luke et al., 2021; Paranawithana et al., 2022; Yücel et al, 2017), and to ensure less reflected light (from deep cerebral layers) is absorbed by the scalp (Paranawithana et al., 2022).

Once all the data was pre-processed and filtered, data was then converted from optical density into haemoglobin concentration changes using the Modified Beer-Lambert Law (mBLL). The mBLL as shown in Figure 14. In its application, the mBLL converts optical data into chromophore concentration changes, namely OxyHb and DeoxyHb (Baker et al., 2014).

Figure 14

MBLL equation

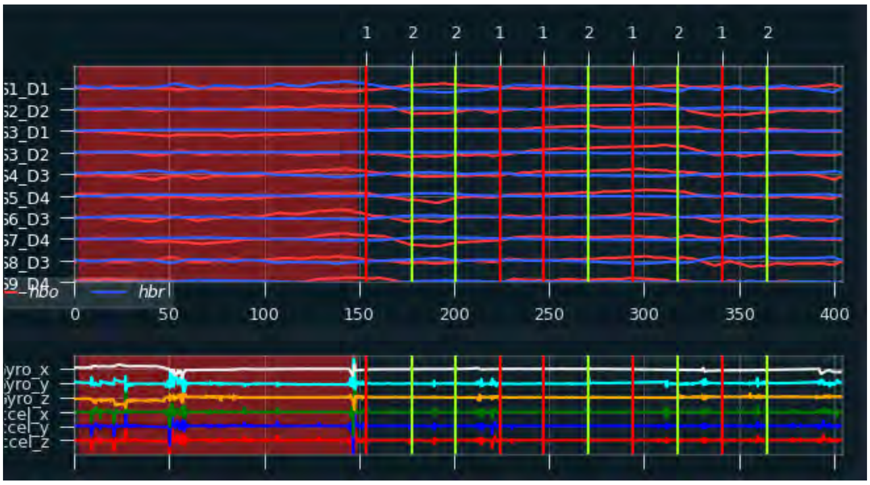
$$OD = -log\frac{I}{Io} = \varepsilon LD_{PF} + G$$

Within the equation, OD refers to optical density (the loss of light intensity). This is measured by log transformations $-log\frac{I}{Io}$ which equals ε: the absorption coefficient of OxyHb and DeoxyHb absorption, of incoming light and outgoing light from the sources and detectors. Further calculations are derived from the length (L) of sources and detectors. The length differential pathlength factor (εLD_{PF}), plus G calculates the loss of photons due to dispersion and changes in haemoglobin concentration (Huppert, 2016; Quaresima et al., 2012). Concerning the above, the LDpf was set at the default value of 6.0. The differential path factor specifically investigates light absorption across each cortical layer as light is released from the light sources and caters for paediatric and geriatric scalp differences (Fabbri et al., 2004). The default value of 6.0 as noted above, further takes into account light absorption variations as determined by underlying cerebral and superficial tissue, thus yielding a fair representation of *light absorption*, *light scattering* and light *dispersion* as light photons are beamed from the sources to the cortex (Cortivision, 2023; Fabbri et al., 2004; Luke et al., 2021).

Once the MBLL was applied, correlation-based signal improvements were run on the data. This algorithm increases the negative correlation between OxyHb and DeoxyHb, thereby reducing unnecessary noise (Cortivision, 2023; Luke et al., 2021). Figure 15 below represents the typical time series used to calculate OxyHb concentration averages for each participant in the research study.

Figure 15

Time Series Display



Note: The time series display for each fNIRS channel after data pre-processing. The red section indicates optical data before the triggers were sent. Within the vertical lines, 1 represents Condition 1 which was Congruent stimuli, and 2 represents Condition 2 which was Incongruent stimuli). The red horizontal lines signify OxyHb (850 nm wavelength) and the blue lines signify OxyHb (760 nm wavelength). For my study, only variations in OxyHb were analysed.

3.7 Data Analysis

Based on the block design format, General Linear Model (GLM) analysis was undertaken to study hemodynamic changes in OxyHb and DeoxyHb on the SCWT. GLM averaging involves integrating the entire fNIRS time series. As previously noted, the block design method, analyses and detects block average differences between brain activation (Condition 1 and Condition 2) compared to 'baseline rest' for OxyHb and DeoxyHb. Block average differences are calculated when participants complete repeated average measures of contrasts between congruent and incongruent measures when compared to baseline or resting states. All data analyses related to signal quality, data pre-processing, mBLL data conversion, and block averaging, were conducted using the CortiPrism software (Cortivision, 2023). Raw fNIRS data (theta value for each block) were then exported from Cortivision to Microsoft Excel using Lab Stream Layering code inbuilt on PsychoPy. Data were further imported to jamovi 2.3.21 (The jamovi 2.3.21 Project, 2022), and JASP 0.17.10 (JASP 0.17.10 Team, 2023) for further analysis[3]. Following suggestions from Yücel et al. (2018), fNIRS data analysis was conducted at two levels, at the *individual* and *group* levels in order to answer Hypotheses 1 and 2.

Statistical tests include the Chi-Square test, Shapiro-Wilk test, Independent Samples T-test, Mann-Whitney test, and Repeated Measures Analysis of Variance (ANOVA). A Chi-Square test compares observed data to expected data, to determine whether data differences occur because there is a relationship between two variables, or if these differences are simply due to chance. It is typically used in clinical settings as it compares experimental and theoretical frequencies in response to a hypothesis, where if a result is found to be significant, it implies that the relationship between the two variables is not due to chance (Tallarida and Murray, 1987; Ugoni and Walker, 1995). The Shapiro-Wilk test was conducted on the data to test for normality, where it is one of the most widely used tests that are beneficial for studies with small sample sizes (n <50), which is the case for this study (Mishra et al., 2019). This test's null hypothesis assumes that data is extracted from a normally distributed population, where if the *p* value is > 0.05, the data is considered normally distributed and the null hypothesis is retained (Mishra et al., 2019). A normal data distribution can be further confirmed by Q-Q plots analysis.

An Independent Samples T-test is used to compare the means of two independent groups and was thus implemented to compare the differences between the yoga and control group in this study. For this test, it is preferred that the groups are randomly assigned to various groups to confirm that differences are due to the intervention, samples sizes should be equal, the data ought to be at an interval level and normally distributed (Ross and Willson, 2017). A non-parametric alternative to the Independent Samples T-test is the Mann-Whitney test, where it was conducted on the data that were not normally distributed in this study. Similar to the Independent Samples T-test, it also tests for group differences, yet they are based on an ordinal

[3] Data Visualizations for T-Test analysis were conducted on DATAtab (DATAtab Team, 2023).

single level, where it does not assume a specific distribution (McKnight and Najab, 2010). Repeated Measures Analysis of Variance (ANOVA) also tests for differences between group means, however it is conducted on one or more variables repeatedly at various time points. This test is able to tackle complex higher-order designs regarding between and within subject components (Park et al., 2009). The repeated measures ANOVA was conducted to identify differences within the channels regarding congruent and incongruent data.

3.8 Ethical Considerations

This study received ethical clearance from the Rhodes University Department of Psychology, and the Rhodes University Human Ethics Committee (Appendix D). Key ethical considerations for the current study included: (1) minimising the risk of Covid-19 transmission, (2) ensuring secure data storage practices for neuroimaging research, and (3) creating personal identification codes for all participants. To reduce the risk of COVID-19 transmission, a Covid-19 questionnaire with participant contact details was used for contact tracing (Appendix I). Other health and safety measures included using hand sanitiser and wearing face masks during the experiment. All other practices including ensuring participant confidentiality, the right to withdraw from the study, and informed consent were adhered to.

Chapter 4. Results

It was hypothesised that participants in the experimental group would indicate faster reaction times and greater response accuracy on the SCWT behavioural measure of sustained attention. It was further hypothesised that the experimental group would display increased OxyHb and decreased Deoxy in the DLPFC when compared to the control group. The above hypothesis was based on the neuroscience literature, investigating brain plasticity and exercise (yoga). Below, the results obtained from this study are discussed in more depth.

4.1 Descriptive Analysis

4.1.1. Demographic Data

Demographic data were obtained from 36 participants in this study. Due to poor fNIRS signal quality, one yoga participant's data was excluded from the group analysis. Moreover, two yoga participants did not complete the demographic questionnaire correctly, and their data were excluded from behavioural analysis on the SCWT. Data indicated more female participants in the yoga (Females: n=15; Males: n=3) and in the control group (Females: n=10; Males: n=8). 60% of participants reported no psychological challenges, with 14% of participants reporting insomnia, 11% reporting generalised anxiety disorder, and major depressive disorder, as well as 16% of participants reporting being on some form of psychotropic medication. Specifically, participants in the yoga group reported using more psychotropic medication (27.8%) compared to controls (5.6%). With regards to sleep hygiene, the yoga group reported sleeping longer (22.2%: 9 – 10 hours of sleep) than the control group (0%: 9 – 10 hours of sleep). Participants in the control group reported greater levels of insomnia (22.2%) compared to the yoga group (11.1%). 64% of the entire sample reported being omnivores, followed by 13.9% flexitarians, 8.3% vegetarians, and 2.8% vegans. Overall, there were slightly more White participants (n=17) than African participants (n=15) in the study. Table 2 summarises the demographic characteristics of the sample.

Chi-Square analysis revealed no significant differences in Sex by Group, $\chi^2 = 2.91$, *p*, = 0.08. Similarly, no differences were found by Group and Age, χ^2 (1) = 0.35, *p* = 0.555, and by Group and Education, χ^2 (5) = 9.22, *p* = 0.1. Chi-Square analysis revealed no significant differences in 5 – 6 hours of sleep by group, χ^2 (1) = 2.31, *p*, = 0.128, or 7 – 8 hours of sleep by group, χ^2 (1) = 0.257, *p*, = 0.612. However, significant differences were found by Group and 0 – 4 hours of sleep, χ^2 (1) = 27.5, *p*, = < 0.001, and by Group and 9 – 10 hours of sleep, χ^2 (1) = 20.8, *p*, = < 0.001. In terms of neuropsychiatric disorders, significant differences were found by Group and ADHD, χ^2 (1) = 31.1, *p*, = < 0.001, by Group and Bipolar II, χ^2 (1) = 31.1, *p*, = < 0.001, and by Group and PMDD, χ^2 (1) = 31.1, *p*, = < 0.001. Similarly, significant differences were found by Group and GAD, χ^2 (1) = 12.6, *p*, = < 0.001, and lastly by Group and MDD χ^2 (1) = 17.9 *p*, = < 0.001.

Table 2

Demographic Characteristics

Sample Characteristics	Control Group		Yoga Group		Full Sample	
	n	%	n	%	n	%
Sex						
Female	10	56.6	15	83.3	25	69.4
Male	8	16.7	3	44.4	11	30.6
Age Range (years)						
18 – 25	10	55.6	10	55.6	20	55.6
25 – 32	0	0	2	11.1	2	5.6
32 – 39	4	22.2	1	5.6	5	13.9
39 – 46	0	0	0	0	0	0
46 – 53	4	22.2	5	27.8	9	25
Height (cm)	173.5 ± 11.95		166.2 ± 10.05		169.9 ± 11.51	
Weight (kg)	76.1 ± 14.48		68.9 ± 11.91		72.6 ± 13.6	
BMI (kg/m^2)	25.5		27.25		26.7	
Ethnicity						

Asian/Indian	1	5.6	1	5.6	2	5.6
Black African	11	61.1	4	22.2	15	41.7
Coloured	1	5.6	0	0	1	2.8
White	5	27.8	12	66.7	17	47.2
Other	0	0	1	5.6	1	2.8
Highest Educational Level						
High School	7	38.9	3	16.7	10	27.8
Undergraduate	2	11.1	7	38.9	9	25
Honours	2	11.1	4	22.2	6	16.7
Masters	1	5.6	3	16.7	4	11.1
PhD	5	27.8	1	5.6	6	16.7
Other	1	5.6	0	0	1	2.8
Home Language						
English	8	44.4	13	72.2	21	58.3
Afrikaans	2	11.1	1	5.6	3	8.3
Chichewa	1	5.6	0	0	1	2.8
isiXhosa	1	5.6	0	0	1	2.8
isiZulu	2	11.1	1	5.6	3	8.3
Ndebele	1	5.6	1	5.6	2	5.6
Sotho	2	11.1	1	5.6	3	8.3

Shona	1	5.6	0	0	1	2.8
Dutch	0	0	1	5.6	1	2.8
Other Spoken Languages						
Monolingual	2	11.1	6	33.3	8	22.2
Bilingual	9	50	5	27.8	14	38.9
Trilingual	5	27.8	5	27.8	10	27.8
Multilingual	4	22.2	1	5.6	5	13.9
Right Handedness[a]	18	100	18	100	36	100
Daily Intake of Cigarettes[a]	0	0	4	22.2	4	11.1
Diet						
Flexitarian	2	11.1	3	16.7	5	13.9
Omnivore	13	72.2	11	61.1	24	66.7
Vegan	0	0	1	5.6	1	2.8
Vegetarian	0	0	3	16.7	3	8.3
Other	0	0	3	16.7	3	8.3
Hours of sleep						
0 – 4 hours	2	11.1	0	0	2	5.6
5 – 6 hours	8	44.4	5	27.8	13	36.1
7 – 8 hours	8	44.4	8	44.4	16	44.4

9 – 10 hours	0	0	4	22.2	4	11.1
Insomnia[a]	4	22.2	2	11.1	6	16.7
Neuropsychiatric Disorder						
ADHD	0	0	1	5.6	1	2.8
Bipolar II	0	0	1	5.6	1	2.8
GAD	3	16.7	4	22.2	7	19.4
MDD	2	11.1	3	16.7	5	13.9
PMDD	1	5.6	0	0	1	2.8
Psychotropic Medication[a]	1	5.6	5	27.8	6	16.7
Herbal Medication[a]	1	5.6	5	27.8	6	16.7
History of TBI[a]	1	5.6	0	0	1	2.8

Note. The above table details the sample and frequency data for the entire population consisting of the yoga group and the control group. $N = 36$ (18 participants per group). Participants were on average 39.5 years old (SD = 12.78).

[a] Reflects the number and percentage of participants answering 'yes' to this question. Values are the mean for BMI (kg/m^2) and the mean ± SD for height (cm) and weight (kg). Abbreviations were used for the following neuropsychiatric disorders: attention/deficit-hyperactivity disorder (ADHD), generalized anxiety disorder (GAD), major depressive disorder (MDD), premenstrual dysphoric disorder (PMDD), and traumatic brain injury (TBI).

4.2 Testing Research Hypotheses

In the current study, three research hypotheses were proposed for the fNIRS and behavioural analysis. For all statistical analyses, the level of statistical significance was set at $p < 0.05$.

4.2.1 Testing Hypothesis 1

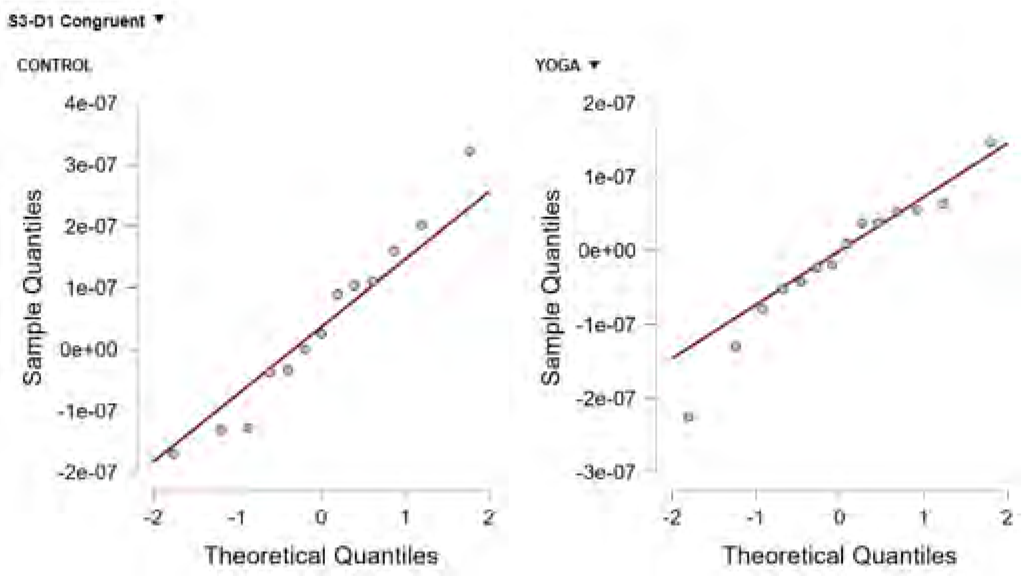
Hypothesis 1 hypothesised that fNIRS individual analysis will indicate greater activation of OxyHb[4] in the yoga participants compared to the control participants in the DLPFC, and decreased DeoxyHb, as measured by fNIRS neuroimaging.

4.2.1.1 Statistical Analysis

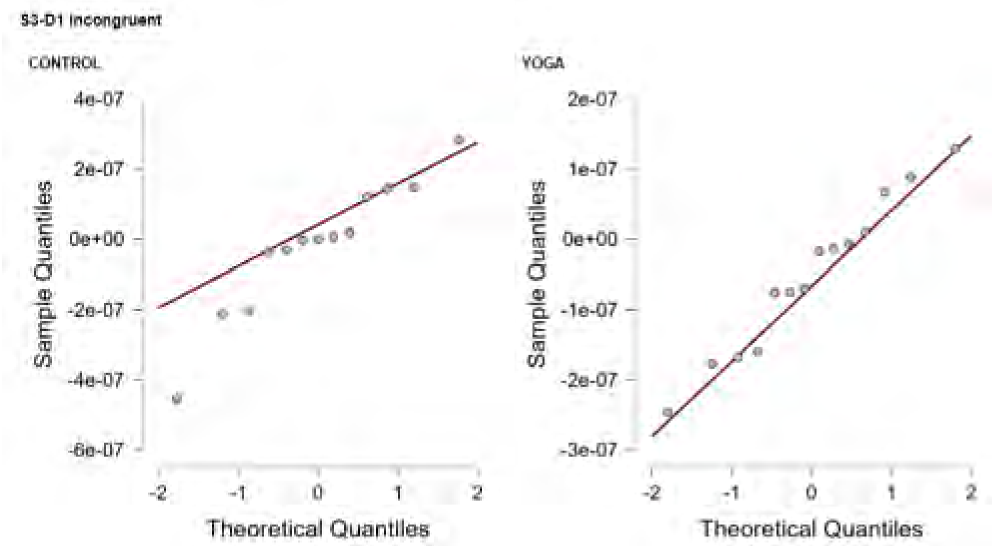
As indicated in Appendix N, four of the twelve channels were normally distributed (S1–D1, S2–D2, S3- D1, S3 – D2), as confirmed by the *Shapiro-Wilk* test. The normal distribution was further confirmed by Q-Q plots analysis as indicated in Figure 16. Figure 16 further details the Q-Q plot distribution for congruent and incongruent data for channel S3-D1. Due to the robust nature of fNIRS neuroimaging, and following suggestions from Yücel et al. (2018), statistical analysis was conducted on all channels, not just the normally distributed ones.

Figure 16

Q-Q plot for Congruent and Incongruent Data



[4] For the purposes of analysis, I analysed OxyHb data and DeoxyHb data, but only report on OxyHb data. All individual analysis where conducted for participants in the yoga and control group, and participants were matched for age, gender, and race.



Note: The above Q-Q plots detail the congruent and incongruent data for channel S3 – D1 for the control (left) and yoga (right) groups.

Individual analyses were conducted for six participants, three participants in the yoga group (n=3) and three participants in the control group (n=3). All participants were matched for age, gender, and race. The following channels in the DLPFC were examined for individual analysis, i.e., S1-D1, S2-D2, S3-D1, S3-D2, S4-D3, S5-D4, S6-D3, S7-D4, S8-D3, S9-D4, S10-D3, and S11-D4.

Once data were pre-processed, as described in *Section 3.6,* simple and GLM averaging was conducted. Simple averaging averages the time course between OxyHb and DeoxyHb. In contrast, GLM averaging is considered a more flexible method and yields enhanced statistical power. The disadvantage of GLM averaging is that it assumes that there is a pre-defined hemodynamic response function (Pinti et al., 2019). Nevertheless, GLM averaging involves the complete integration of the fNIRS time series, allowing different hypotheses to be tested by various statistical tests. Furthermore, GLM averaging contains improved inference accuracy by including a range of covariates (head movements, behavioural data, and short-separation channels) (Pinti et al., 2019). For my analysis, only OxyHb data between the two groups was analysed concerning differences between congruent (Condition 1) and incongruent (Condition 2) stimuli. Average data for these conditions at a group level (yoga vs control) are analysed in *Hypothesis 2*. Figure 17 below illustrates the simple averaging model, whereas Figure 18 illustrates the GLM, as applied for the individual analysis.

Figure 17

Simple Averaging Model

Note: The red line indicates OxyHb during the congruent condition (Condition 1). The green spectra indicate the OxyHb during the incongruent condition (Condition 2) for channel S1–D1(CortiPrism Software).

Figure 18

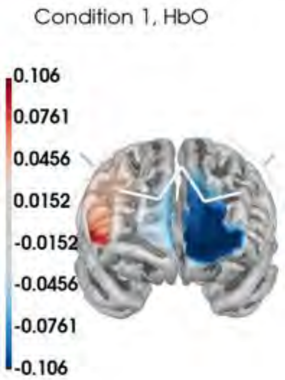
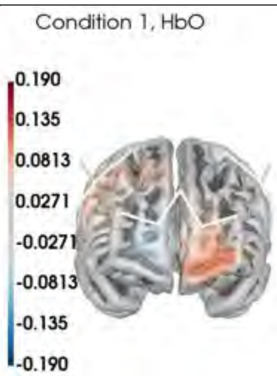
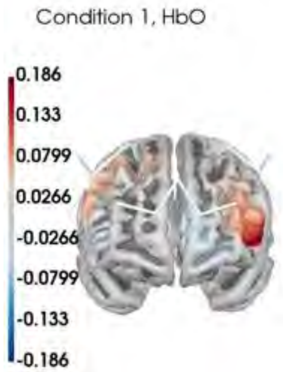
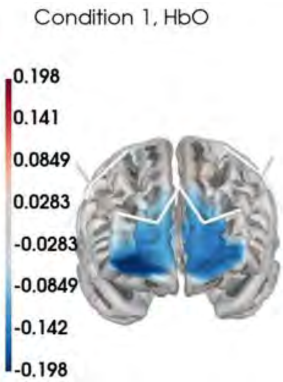
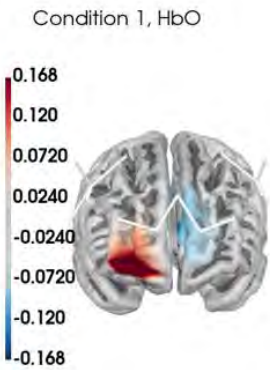
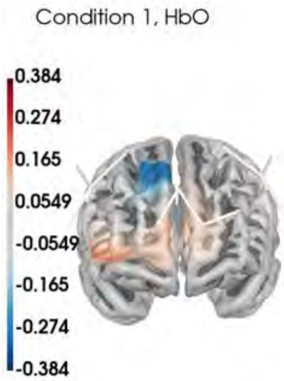
General Linear Model Averaging

Note: The red line indicates OxyHb during the congruent condition (Condition 1). The green spectra indicate OxyHb during the incongruent condition (Condition 2) for channel S1–D1(CortiPrism Software).

For the individual analysis, I hypothesised that the yoga participants (three individual participants) would display higher OxyHb and lower DeoxyHb in the DLPFC when compared to the participants in the control group (three individual participants). Brain visualisations for three yoga and three control participants are displayed next to each other in Tables 3 and 4 below. Tables 3 and 4 display the OxyHb response that occurred during congruent and incongruent stimuli under GLM averaging.

Table 3

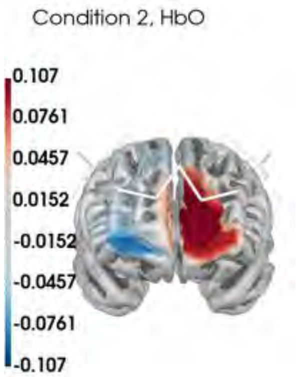
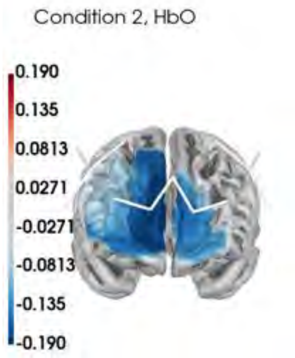
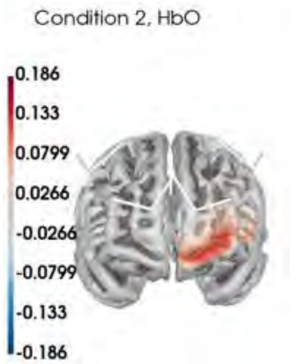
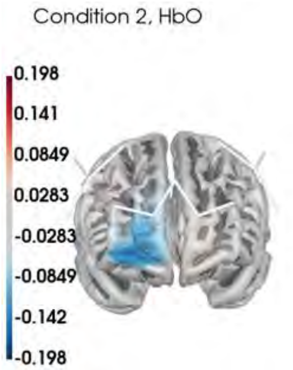
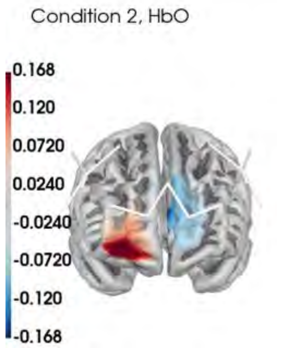
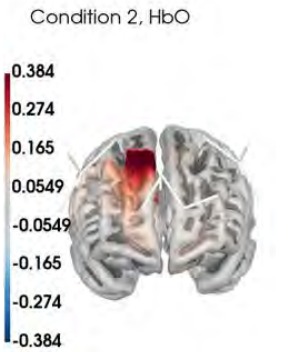
OxyHb Responses to Congruent Condition (Condition 1)

Group	Participant 1	Participant 2	Participant 3
Yoga			
Control			

Note: Red spectra indicate OxyHb, while blue spectra symbolise the DeoxyHb concentration. Hemodynamic response during the congruent condition indicates that the right and left DLPFC was activated in all three yoga participants, whereas the first yoga participant had increased DeoxyHb in the left DLPFC. Regarding the control participants, the first participant displayed an increase in DeoxyHb, whereas participants two and three display an increase in OxyHb in the right DLPFC.

Table 4

OxyHb Responses to Incongruent Stimuli (Condition 2)

Group	Participant 1	Participant 2	Participant 3
Yoga			
Control			

Note: Red spectra indicate OxyHb, while blue spectra equates to DeoxyHb concentration. Hemodynamic response during the incongruent condition shows that the yoga participants had an increase in oxygen in the left DLPFC, with an increase in DepxyHb predominantly observed in the right DLPFC. While the control group displayed more activation in the right DLPFC, as well as increased DeoxyHb in the left and right DLPFC.

Although there was greater OxyHb activation in yoga Participant 3 for the congruent condition, and yoga Participant 1 for the incongruent condition, the hypothesis that yoga participants matched by age, and gender would perform better than control on OxyHb measures was disproven. Instead of demonstrating increased OxyHb and decreased DeoxyHb, at the individual level, the yoga group displayed more DeoxyHB concentrations, across larger cerebral regions, and more intensely than the control group. Thus, the null hypothesis is retained.

4.2.2 Testing Hypothesis 2

Hypothesis 2 stated that fNIRS group analysis will indicate greater activation of OxyHb and decreased DeoxyHb in the DLPFC, for the yoga group when compared to the control group.

4.2.2.1 Statistical Analysis

Simple averaging and GLM averaging were conducted for *all participants*, following the steps mentioned in the pre-processing stage (refer to *Section 3.6*). All averaged data in the form of theta values per channel (source and detector) were converted to Excel, and exported to JASP 0.17.10 for statistical analysis. Once the *Shapiro-Wilk test* analysis was conducted on the data to test for normality, Independent Samples T-test measures were performed on the data. The Mann-Whitney test was conducted for the data that was not normally distributed. Repeated Measures ANOVA analysis was further conducted to identify differences within the channels (congruent vs incongruent). The above statistical procedures are further discussed in the sections that follow.

4.2.2.1.1 Independent Samples T-Test

As indicated in Table 5 Independent Samples T-Test analysis, (two-tailed; equal variances assumed) indicated no significant difference between the yoga group and the control group on any of the dependent variable channels of interest (Channel S1-D1 congruent, $t(-0.710) = 5$, $p = 0.509$, 95% confidence interval [-2.050, 1.015]; Channel S1-D1 incongruent, $t(0.146) = 5$, $p = 0.890$, 95% confidence interval [-1.392, 1.604]; Channel S2-D2 congruent, $t(0.203) = 6$, $p = 0.846$, 95% confidence interval [-1.292, 1.576]; Channel S2-D2 incongruent, $t(1.164) = 6$, $p = 0.289$, 95% confidence interval [-0.688, 2.326]; Channel S3-D1 congruent, $t(1.113) = 25$, $p = 0.276$, 95% confidence interval [-0.340, 1.189]; Channel S3-D1 incongruent, $t(0.573) = 25$, $p = 0.572$, 95% confidence interval [-0.593, 0.976]). However, the yoga group has lower values for most of the dependent variables.

Table 5

Independent Samples T-Test Results

Dependent variable						95% CI for Cohen's d	
	T	Df	*p*	Cohen's d	SE Cohen's d	Lower	Upper
S1-D1 congruent	-0.710	5	0.509	-0.542	0.795	-2.050	1.015
S1-D1 incongruent	0.146	5	0.890	0.111	0.765	-1.392	1.604
S2-D2 congruent	0.203	6	0.846	0.148	0.732	-1.292	1.576
S2-D2 incongruent	1.164	6	0.289	0.850	0.778	-0.688	2.326
S3-D1 congruent	1.113	25	0.276	0.429	0.394	-0.340	1.189
S3-D1 incongruent	0.573	25	0.572	0.221	0.388	-0.593	0.976
S3-D2 incongruent	1.424	31	0.165	0.498	0.359	-0.202	1.190

Note: Results exhibit that there was no statistical significance between the yoga and control group in the normally distributed channels.

4.2.2.1.2 Mann-Whitney Test

The results of the descriptive statistics indicate that the yoga group had lower values for the dependent variable, fNIRS channel S3 – D2 congruent (*Mdn* = -2.881×10^{-8}) than the control group (*Mdn* = 4.384×10^{-7}). Mann-Whitney U-Test analysis indicated no significant difference between the yoga and control group, participants on any of the with respect to the fNIRS dependent measures. Contrary to expectation, most of the group channel analyses were statistically insignificant, as indicated in channel S3-D2 congruent: yoga (*Mdn* = -2.881×10^{-8}); control (*Mdn* = 4.384×10^{-7}), $U = 164$, $p = .307$, $r = 0.215$. Thus, regarding Hypothesis 2, the null hypothesis is retained. As indicated in Table 6 below, no significant mean differences were noted in the yoga and control group in terms of OxyHb activation.

Table 6

Mann-Whitney Test Results

Dependent variable	W	*P*	Rank-Biserial Correlation	SE Rank-Biserial Correlation	95% CI for Rank-Biserial Correlation	
					Lower	Upper
S3-D2 congruent	164.	0.307	0.215	0.202	-0.181	0.551
S4-D3 congruent	137.	0.812	-0.052	0.198	-0.418	0.329
S4-D3 incongruent	185.	0.170	0.280	0.198	-0.105	0.593
S5-D4 congruent	160.	0.832	0.046	0.195	-0.330	0.409
S5-D4 incongruent	191.	0.216	0.248	0.195	-0.134	0.566
S6-D3 congruent	147.	0.858	-0.039	0.195	-0.403	0.335
S6-D3 incongruent	177.	0.443	0.157	0.195	-0.226	0.498
S7-D4 congruent	164.	0.732	0.072	0.195	-0.306	0.430
S7-D4 incongruent	183.	0.335	-0.196	0.195	-0.187	0.528
S8-D3 congruent	191.	0.219	0.248	0.195	-0.134	0.566
S8-D3 incongruent	176.	0.463	0.150	0.195	-0.232	0.493
S9-D4 congruent	123.	0.335	0.196	0.195	-0.528	0.187
S9-D4 incongruent	184.	0.318	0.203	0.195	-0.181	0.532
S10-D3 congruent	174.	0.503	0.137	0.195	-0.245	0.483
S10-D3 incongruent	176.	0.463	0.150	0.195	-0.232	0.493
S11-D4 congruent	149.	0.909	-0.026	0.195	-0.392	0.347
S11-D4 incongruent	150.	0.935	-0.020	0.195	-0.387	0.353

Note: Results exemplify that there was no statistical significance between the yoga and control group in the data that were not normally distributed.

4.2.2.1.3 Repeated Measures ANOVA

In addition to the above analysis, a repeated measures analysis of variance (ANOVA) was performed to determine the main effects and interactions of the conditions. Within subjects' effects demonstrated that there was no significance between the groups and the fNIRS channels, $F\ (23,69) = 0.428$, $p = 0.987$. Similarly, between subjects' effects demonstrated that there was no significance between the yoga and control group on the fNIRS channels, *F* (1,3) = 0.097, *p* = 0.776. Table 7 illustrates these findings below.

Table 7

Repeated Measures ANOVA Results

Source					
	Df	SS	MS	*F*	*p*
Between Groups	23	$9.409{\times}10^{-16}$	$9.409{\times}10^{-16}$	0.428	0.776
Within Groups	1	$5.504{\times}10^{-14}$	$2.393{\times}10^{-15}$	0.097	0.987
Total	24				

Note: Results express that there were no significant differences within subjects and between subjects' effects for all channels in the yoga and control group.

In conclusion, Hypothesis 2 was disproven. Group analysis indicates that the yoga group did not exhibit a statistically significant ($p < 0.05$) increase in OxyHb and decreased DeoxyHb in the DLPFC when compared to the control group. Therefore, the null hypothesis is retained.

4.2.3 Testing Hypothesis 3

Hypothesis 3 stated that the yoga group will perform significantly better in reaction time and response accuracy in the SCWT when compared to the control group.

4.2.3.1 Descriptive Analysis

As indicated in Table 8, the yoga group displayed slower reaction times (*M* = 1,518; *SD* = 0,09) for congruent stimuli compared to the control group (*M* = 1,083; *SD* = 0,12). The yoga group had a slightly faster response for incongruent stimuli (*M* = 1,104; *SD* = 0,14), compared to the control group (*M* = 1,120; *SD* = 0,14). Response accuracy data indicates that the yoga group had higher response values for congruent stimuli (*M* = 25.9, *SD* = 2.93) compared to the control group (*M* = 24.7 =, *SD* = 5.90). There was also greater response accuracy in the yoga group on incongruent stimuli (*M* 23.0 =, *SD* = 6.22) compared to the control group (*M* = 17.7, *SD* = 6.64).

Table 8

SCWT Performance Results

Group	Reaction time (sec) (M±SD)		Response Accuracy (M ± SD)		Accuracy (%)	
	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
Yoga	1,518 ± 0,09	1,104 ± 0,14	25.9 ± 2.93	23.0 ± 6.22	86.3 ± 11.2	76.6 ± 26.9
Control	1,083 ± 0,12	1,120 ± 0,14	24.7 ± 5.90	17.7 ± 6.64	82.2 ± 23.9	58.8 ± 37.5

Note: Data are expressed as means ± standard deviations. Results for reaction time are displayed in seconds (sec) and results for response accuracy are displayed in means and percentages.

4.2.3.2 Statistical Analysis

Reaction Time: A two-tailed t-test for independent samples (equal variances assumed) was run to investigate group differences (yoga and control group) on the dependent variable, Congruent Reaction Time. The Levene test of equality of variance was met (p = 0.659). The analysis indicated that group differences regarding the dependent variable, Congruent Reaction Time, were not statistically significant, $t(34)$ = -1.04, p = 0.307, 95% confidence interval [-1.004, 0.322], Cohen's d (0.35). The null hypothesis is thus retained.

Likewise, a two-tailed t-test for independent samples (equal variances assumed) was run investigating yoga and control group differences on the dependent variable, Incongruent Reaction Time. The Levene test of equality of variance was met (p = 0.414). Analysis indicated that group differences with respect to the dependent variable Incongruent Reaction Time were not statistically significant, $t(34)$ = -0.483, p = 0.632, 95% confidence interval [-0.161, -0.814] Cohen's d (0.16). Table 9 below illustrates the results of the independent samples t-test. Figure 19 illustrates the information in the form of box plots.

Table 9

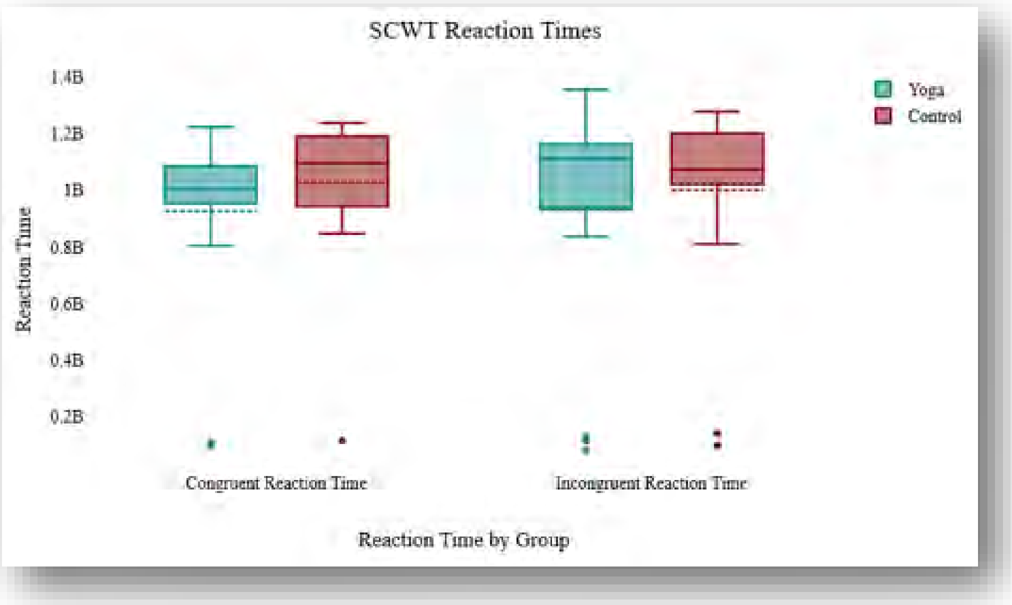
Independent T-Test Reaction Time for Congruent and Incongruent Stimuli

Group	Reaction Time (sec)	
	Congruent	Incongruent
Df	34	34
p-value	0.307	0.632
Yoga	1,51 ± 0,09	1,10 ± 0,14
Control	1,08 ± 0,12	1,12 ± 0,14

Note: Mean and standard deviations are expressed as (M ± SD). Results are in seconds (sec) and indicate that there was no significant difference between the yoga and control group for reaction time.

Figure 19

Reaction Time Illustrated in Boxplots



Note: The above bar plots indicate that although there was no significant difference in reaction time (sec), the control group has a slightly longer reaction time during congruent and incongruent stimuli when compared to the yoga group.

Response Accuracy: A two-tailed t-test for independent samples (equal variances assumed) was run to investigate group differences (yoga and control group) on the dependent variable, congruent response accuracy. The Levene test of equality of variance was met (p = 0.212). Results indicated that group differences with respect to the dependent variable Congruent Correct Accuracy were not statistically significant, $t(34) = 0.79$, $p = 0.437$, 95% confidence interval [-0.401, 0.918], Cohen's *d* (0.26). The null hypothesis for my study is thus retained.

Similarly, a two-tailed t-test for independent samples (equal variances assumed) was run investigating yoga and control group differences on the dependent variable, Incongruent Response Accuracy. The Levene test of equality of variance was met (p = 0.525). Results indicated that group differences with respect to the dependent variable Incongruent Correct Accuracy were statistically significant, $t(34) = 2.486$, $p = 0.018$, 95% confidence interval [0.109, 1528], Cohen's *d* (0.829), suggesting a large effect. The alternative hypothesis for my study is thus retained. Table 10 demonstrates the results from the independent samples t-test for response accuracy and Figure 20 illustrates visualisations of the correct response through boxplots.

Table 10

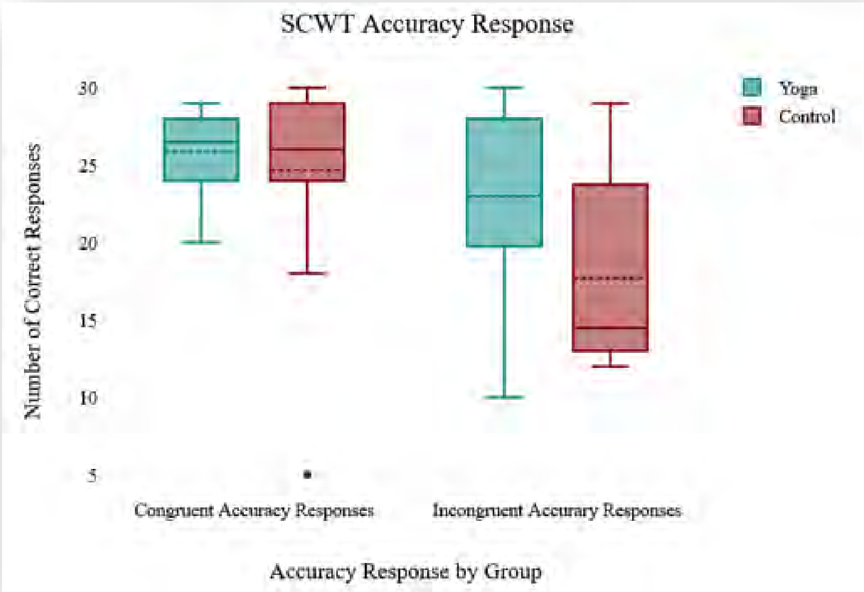
Response Accuracy for Congruent and Incongruent Stimuli

Group	Response Accuracy	
	Congruent	Incongruent
Df	34	34
p-value	0.437	0.018*
Yoga	25.9 ± 2.93	23.0 ± 6.22
Control	24.7 ± 5.90	17.7 ± 6.64

Note: *p < 0.05. Mean and standard deviations are expressed as (M ± SD). Results indicate that there was a significant difference between the yoga and control group (p = 0.018) in incongruent stimuli response accuracy. There was no significant difference found in congruent stimuli between the groups.

Figure 20

Correct Response Per Group and Condition



Note: The yoga group had a slightly higher number of correct responses for the congruent stimuli and performed significantly better during incongruent stimuli when compared to the control group.

Although no significant difference ($p < 0.05$) was found for congruent and incongruent reaction time, as well as for congruent response accuracy between the yoga and control group, results indicate that there was a significant difference in *incongruent response accuracy* ($p = 0.018$) between the yoga and control group. Thus, the hypothesis that the yoga group will perform better than the control group on the SCWT is retained, in terms of the dependent variable, incongruent response accuracy.

Chapter 5. Discussion

The purpose of this study was to gain a better understanding of whether short-term yoga practice could improve overall performance in sustained attention. In comparison to the control group, it was hypothesised that the yoga group would experience an increase in OxyHb and a reduction in DeoxyHB in the DLPFC, as indicated by fNIRS. Furthermore, it was hypothesised that regular yoga practice improves behavioural outcomes during SCWT performance, i.e., faster reaction times and heightened response accuracy, when compared to the control group.
Th main findings from the current study were that: (1) fNIRS individual analysis and (2) fNIRS group analysis indicate no significant differences ($p < 0.05$) between the yoga and the control group in neuroimaging data. Lastly, findings from the SCWT indicated insignificant differences between the groups in terms of reaction time, and congruent response accuracy. Nonetheless, significant differences ($p = 0.018$) were found in *incongruent response accuracy,* with the yoga group performing better than the controls. The abovementioned findings will be discussed further in the sections that follow.

5.1 Hemodynamic Response Measurements

In contrast to other fNIRS studies (e.g., Dev et al., 2019; Dybvik et al., 2021; Jiang et al., 2021), there were no significant increases in OxyHb or decreases in DeoxyHb in the DLPFC observed in the yoga group, when compared to the control group in this study. These findings however are further supported by Bhargav et al. 2014, who compared a yoga group (diagnosed with schizophrenia to a healthy control group (N=36). The yoga group had 15 days of yoga experience, where fNIRS results indicated no significant difference in OxyHb between the yoga and control group. In another study, Bellissimo et al. (2020) examined the effects of fast and slow-*breathing* yoga on twenty participants. The authors also observed no significant increase in OxyHb in the left and right PFC during slow yoga *breathing* in the yoga group, when compared to the control group.

The current study's findings suggest that the yoga group may have found an alternative strategy to enhance sustained attention during a cognitively demanding task. Research, conducted by Dybvik et al. (2021), further supports this proposed theory. The authors discovered increased cerebral activation in the left PFC, which was also observed in this study's yoga participants. According to Dybvik et al. (2021), increased activity in the left PFC suggests a state of mental exploration, created to seek novel and unknown alternatives to make a difficult yoga pose easier. This is thought to occur by attempting to find other ways to change the position of their yoga pose or by activating different types of muscles. Concerning this study, increased activity in the left PFC suggests that the yoga participants underwent a state of mental exploration during the SCWT to find an easier way to combat the incongruent stimuli and the Stroop effect. Dybvik et al. (2021) also note that insignificant OxyHb in the DLPFC is due to participants remaining attentive to the task, yet not finding an alternative way to tackle the task at hand. Thus, in the current study, although the yoga participants displayed OxyHb concentrations during their individual analysis, fNIRS group analysis signifies that they were insignificant. Therefore, proposing that they remained attentive to the SCWT but did not endure drastic measures to find alternative solutions.

Possible alternative strategies that the yoga group could have used include (1) task rehearsal, (2) single-letter focus and (3) visual blurring (Palfi et al., 2022). Task rehearsal occurs when participants use working memory and goal maintenance to remind themselves of the instructions, for example, to focus on the 'colour ink'. Working memory and goal maintenance is located in the left PFC, therefore supporting why the yoga participants had increased activation in this brain region. Another method which allows for easier in identification occurs when one focuses on a specific letter within the word itself. Lastly, the visual blurring strategy transpires when participants relax the muscles around them (Palfi et al., 2022). This results in observing the words as meaningless symbols, which aids in reducing the Stroop effect (Palfi et al., 2022). This strategy may also influence top-down attentional processing. After the experiment was completed, some of the yoga participants informed the researcher that they used visual blurring to tackle the SCWT. This, therefore, reduced the interference effect in incongruent stimuli and is a non-drastic approach resulting in increased activation in the left PFC. Since participants had less semantic conflict by using the visual blurring strategy, it offers a possible reason why there was a non-significant difference in OxyHb in the DLPFC between the yoga and control group.

Taken together, the findings indicate that yoga participants might have had improved top-down attentional processing. Yoga embodies meditation, and it is thought to 'train' selective (seen by selecting specific information to focus on) and sustained (by continuous monitoring of the meditative object) attention (Braboszcz et al., 2013). Moreover, yoga is considered to be a state training approach, as it trains one to have a 'focused gaze control'. This typically occurs when one gazes at an external object to hold a yoga pose more efficiently. This type of training is thought to improve cognitive flexibility, visual discrimination, and spatial attention, and to enhance tactile accuracy (Braboszcz et al., 2013; Foster & Eimer, 2005; Gherri & Foster, 2014). Due to this effect, the yoga group was able to voluntarily focus their attention on specific stimuli on the SCWT screen by redirecting their gaze toward a target (bottom word in the SCWT). This strategy possibly activated the frontal oculomotor network and supplementary eye fields, resulting in improved performance in monitoring and inhibitory control (Thakker et al., 2014). Further to the above, activation of the frontal oculomotor network may have allowed the yoga group to prevent saccadic eye movements towards distracting stimuli (such as the meaning of the top word and not the colour ink it was written in) (Hikosaka et al., 2000). Therefore, this speculation may have translated into enhanced SCWT response accuracy in the yoga group due to focused gaze control. The above may be a possible reason for a non-significant OxyHb level in the DLPFC as increased OxyHb might have increased in the occipital lobes region, which was not covered by the fNIRS optodes experimental design used in the study.

Another interpretation of the non-significant OxyHb in the DLPFC between the yoga and control group is that the yoga group was compared to a control group that had higher numbers of bilingual participants. This theory is supported by other studies (Kousaie et al., 2014; Li et al., 2023) which found that bilingual participants had enhanced brain activation during fNIRS recordings when compared to monolinguals. These authors concluded that bilingual participants experienced less Stroop interference because of improved executive functioning in terms of inhibitory control, task switching, and planning (Kousaie et al., 2014). This, therefore, may have caused the control group to have higher amounts of OxyHb, thus resulting in a non-significant difference between the two groups. In this study, 50% of the control participants were bilingual, 27% were trilingual, and 22% were multilingual (ability to speak three and more languages), whereas 33% of the yoga participants were monolingual, suggesting that there might have been improved CBF in the control group, i.e., due to bi- and multilingualism.

Likewise, the non-significant OxyHb concentration may be explained by the idea that the type of yoga style frequently practised by research participants could have played a significant role in the reduced fNIRS brain activation observed in the study. For instance, more than half (55.6%) of the yoga group practised fast-paced movement styles such as Vinyasa and Ashtanga, where research (Schmalzl et al., 2018) suggest that slow and rhythmic breathing from slow-paced yoga styles such as Hatha yoga, improves parasympathetic dominance and cognitive control. This suggests, that since the most frequently practised yoga styles are fast-paced, participants might not have been able to fully reap the cognitive benefits of such complex yoga styles. In this study, only 38.9% practised slow-paced and breath-focused yoga styles, (specifically Restorative, Hatha, and Yin yoga), which are more beneficial for inexperienced yogis. The above assertion is supported by Schmalzl et al. (2018), who found that sustained attention only improved in the breath-focused yoga group. From this evidence, breath-focused and slow-movement yoga styles allow one to receive more cognitive benefits as they enable yogis to ensure controlled breathing, meditation, and mindfulness are in sync with body movements, as opposed to faster movement-focused yoga styles which were common in this sample.

5.2 Behavioural Measurements

Behavioural measures of sustained attention were measured by the SCWT. This study's SCWT findings are further supported by previous researchers who also researched yoga and used the SCWT (Eyre et al., 2017; Nilsoge et al., 2016; Phansikar et al., 2023, Telles et al., 2013). In contrast to the current study's behavioural findings, Dev et al. (2019), Froeliger et al. (2012), Oken et al., 2006b, and Taylor et al. (2017) also administered the SCWT and compared yoga and control groups, yet they found no significant difference with respect to reaction time and response accuracy. In the section that follows, other studies that found similar results will be discussed, followed by explanations regarding reaction time and response accuracy.

5.2.1 SCWT Reaction Time

Even though statistically insignificant, behavioural results from the SCWT indicated that the yoga group performed slightly faster on congruent and incongruent reaction times when compared to controls. Similar to the current study, Phansikar et al. (2023) researched whether there was a difference between yoga and control groups concerning executive functioning. Their RCT indicated that although non-significant, the yoga group had slightly higher reaction times in the SCWT than the control group.

It has been proposed (refer to *Section 5.1*) that one explanation for these statistically insignificant differences between groups might be explained by the higher number of bilinguals and multilinguals in the control group when compared to the yoga group. In this context, the number of spoken languages has a positive effect on executive functioning, specifically response inhibition, task-switching, and planning (Kousie et al., 2014). This unexpected inhibitory enhancement is perhaps why there were fewer cases of the Stroop effect in the control group (Kousaie et al., 2014; Li et al., 2023). The Stroop effect occurs due to delayed processing seen during incongruent stimuli, where bilingual individuals have experienced interference between two or more languages (Ghimire et al., 2014), therefore regularly practising top-down attentional processing. The control group had higher levels of tertiary education, which may have impacted the reaction time on the SCWT (refer to Table 4). This is further supported by studies, such as Savaş et al. (2020) who indicate that there is a correlation between reaction times on the SCWT and the individual's level of education. Additionally, if the visual blurring strategy was used, this method leads to faster reaction times, due to the reduced Stroop effect, which was evident in this study's yoga group (Palfi et al., 2022). As there was a potential reduced Stroop effect, research by Braboszcz et al. (2013) has found that this enhances response accuracy.

5.2.2 SCWT Response Accuracy

Response accuracy was significantly higher in the yoga group when compared to the control group. Nilsoge et al. (2016) conducted a cross-sectional study to examine the extent to which yoga improves attention and verbal memory in pre-adolescents (N=80) when compared to a control group (N=80). In contrast to the control group, the yoga group performed significantly better (p <0.0001) in response accuracy. Likewise, Eyre et al. (2017) conducted an RCT to investigate whether Kundalini yoga could improve mild cognitive impairment in healthy participants (N=81). The authors found similar results to this study, where there was a significant difference (p = 0.05) between the yoga and control group in SCWT response inhibition. Additionally, the RCT by Telles et al. (2013) investigated the effects of yoga and physical exercise on cognition, by comparing a yoga group to a physical exercise group, in a population of healthy children (N=98). Telles and colleagues (2013) found significant ($p < 0.01$) improvements in the SCWT (regarding colour-word naming) in the yoga group in the post-test when compared to the pre-test.

These findings suggest that yoga may have enhanced neuroplasticity in the brain, resulting in overall improvements in sustained attention, inhibitory control (regarding cognitive interference), cognitive flexibility, processing speed, and working memory. There were also four yoga instructors included in this study. Studies have shown that yoga instructors exhibit enhanced problem-solving skills, visual-spatial discrimination, and attention, which ultimately, improve their ability to engage with incongruent stimuli on the SCWT (Narayana, 2019). The state training approach of yoga entails that visual perception is improved (by practising ‘focused gaze control’). Thus, this reduces the amount of attention needed for a task like the SCWT. Subsequently, state training increases attentional resources for sustained visual attention, which leads to heightened adaptive functioning regarding incongruent stimuli (Schmalzl et al., 2018). In this sense, the adaptive mechanism that took place could have been the visual blurring strategy. This proposes that yoga delays age-related cognitive decline, and increases neuroplasticity in the occipital lobe, in turn, allowing for improved measures of visual-based sustained attention.

Another theory as to why the yoga group performed better in response accuracy is due to the yoga group being less stressed. Research by Schmalzl et al. (2018) found that yogis had less stress than controls. Fewer stress results in a positive impact on parasympathetic dominance, which enhances attentional regulation. The authors found a correlation between stress, reduced reaction time, and increased perceptual sensitivity. Therefore, enhanced perceptual sensitivity could explain why the yoga group had reduced reaction time, yet higher response accuracy. Thus, the control group might have been more stressed (as they do not engage in activities to reduce stress, such as yoga) thus this may have hindered their ability to sustain attention and resulted in performing worse during incongruent stimuli.

In addition to improved visual perception, yoga practice might have improved motor control in the yoga group, when compared to the control group. Yoga is said to be a type of exercise requiring large amounts of motor control, which when achieved, yoga fosters self-control, and stress reduction, and improves attention, and concentration (Peck et al., 2005). Thus, exercise which emphasises motor control, enhances sustained attention by activating the associated brain region directly after exercise (Budde et al., 2008). As yoga enhances attention and information processing, it, therefore, improves discrimination ability, resulting in superior neuroprocessing and attentional allocation (Chou & Huang, 2017). Thus, the yoga group overcame incongruent interference, which resulted in higher response accuracy and fewer errors, than the control group. Neurochemical changes could have also occurred in the yoga group, where yoga increases serotonin and dopamine and decreases cortisol, which improves inhibition and attentional functioning by regulating levels of arousal (Del Campo et al., 2011; Pal et al., 2014). Thus, yoga may have enhanced motor control, cognitive flexibility, and sustained attention, and therefore, the yoga participants performed with fewer errors. From the above, it can thus be hypothesised that regular yoga practice leads to functional neuroplastic alterations in the DLPFC, thus enhancing concentration and the ability to sustain attention by creating a balance between top-down and bottom-up attentional processing.

Along with neuroplastic changes in the brain, yoga may increase insular volume, thereby, decreasing physical pain, and leading to improved cognition, therefore potentially improving the ability to sustain attention for lengthy periods, as it is difficult to do that in the face of chronic pain. Additionally, yoga is known to strengthen joints, improve musculoskeletal conditions, and the lower back, which are the three most common areas where the elderly experience severe chronic pain, which might be why controls had worsened response accuracy (Chang et al., 2016; Cheung et al., 2017; Molton & Terrill, 2014; Ward et al., 2013). One control participant noted that on the day of the experiment, they had severe physical pain, whereas another mentioned that they were frustrated, all of which could have impacted their results. Of the yoga participants, one mentioned a neutral affect, and another was frustrated, where attentional functioning is said to operate best with a positive mood.

Demographic results indicate that the yoga group slept more than the control group. The yoga group indicated that 44.4% slept for 7 to 8 hours and 22.2% slept for 9 to 10 hours. Whereas 44.4% of the control group slept for 5 to 6 hours and 11.1% slept for 0 to 4 hours. Optimal brain function occurs with an average of 7 hours of sleep (Tai et al., 2022). Along with less sleep, more control participants suffered from insomnia 22%, whereas only 11% experienced insomnia in the yoga group. Thus, more sleep and less insomnia could have resulted in the yoga group displaying optimal concentration and the ability to sustain attention for a longer period, as yoga is known to improve sleep quality and duration (Wang et al., 2020).

Although the participants were matched by age and no significant age differences were found, the yoga group had a slightly older age range than the control group, where the control group had more participants that were more educated than the yoga group with five participants holding PhD's in the control group and only one participant with a PhD in the yoga group. However, the control group consisted of an increased number of younger participants in high school, while the yoga group contained more undergraduate participants. Yet, although the yoga group was slightly older, and had fewer PhDs, they still outperformed the control group regarding response accuracy, thus suggesting a link between yoga practice and response accuracy. Age is associated with slower reaction times in the SCWT (Savas et al., 2020).

Likewise, educational differences between participants are supported by the number of errors and spontaneous corrections, suggesting a relationship between educational attainment and inhibitory control (Savas et al., 2020).

Moreover, females (n=15) outnumbered males (n=3) in the yoga group. Previous research has found differences in attention between males and females, owing to CBF differences in hormones, such as oestrogen (Krejza et al., 2001; Newman et al., 2020). CBF is strictly regulated to ensure that OxyHb consistently reaches the brain to satisfy metabolic demands (Hamer et al., 2020). Additionally, CBF differences were found in male and female athletes that experienced concussions in the past, in that females had improved CBF compared to males even though both groups had a history of concussions (Hamer et al., 2020). This possibly suggests that increased oestrogen levels in the follicular phase of the menstrual cycle may have a neuroprotective role regarding brain injuries (Hamer et al., 2020). Therefore, this possibly suggests that when females are in the late follicular phase, they could perform better than males on sustained attention tests due to increased CBF. Cyclooxygenase (a basal CBF controlling enzyme) functions equally in both males and females, therefore there is an unidentified vasodilator mechanism that maintains a slightly higher CBF in females at rest when in the early follicular phase when sex hormones are least different to males (Peltonen et al., 2015; Peltonen et al., 2016). Two studies have indicated that yoga practice may have the ability to alter the neuroendocrine system by increasing the level of oestrogen in perimenopausal and menopausal females (Afonso et al., 2016; Archong & Plianbangchang, 2021), and oestrogen has been found to stimulate neurogenesis in the dentate gyrus, a part of the hippocampus, in female rodents (Tanapat et al., 1999). One study even indicated that as little as four months of yoga (done twice weekly) increased oestrogen in postmenopausal females compared to females with no yoga experience in a study that compared females (Afonso et al., 2016). This may result in overall amplified CBF and possible improved performance in sustained attention assessments regarding response accuracy.

5.3 Limitations

Experimentally, some technical challenges were noted in the current study. Firstly, due to the costs of neuroimaging research, one fNIRS neuroimaging device was used to collect data, which resulted in cases of miscommunication on the days of data collection for the experiment. In some instances, due to the unreliability of the network, the fNIRS device sometimes lost Bluetooth connectivity, between the Lab Streaming Layering causing disturbances during signal recording which may have tampered with the results. Further to the above, during overcast days, the fNIRS displayed more channels with low signal quality, which is believed to be from the laptop's brightness reflecting on the fNIRS and causing heightened instrumental noise. Moreover, the researcher initially aimed to use the Continuous Performance Test (CPT) as a measure of sustained attention. However, numerous problems occurred during the programming of the assessment on PsychoPy, resulting in the SCWT being chosen as an alternative tool for assessing sustained attention. It is recommended that future studies consider using the CPT to assess sustained attention, a standard practice in some studies assessing attention (Hsieh et al., 2005; Mass et al., 2000). Moreover, many participants were not able to come during the morning for the experiment (which is associated with improved cognition) and were spread out over the afternoon and evening, which could have impacted performance.

As suggested above, the study is not without methodological limitations. During fNIRS instrumentation, participants with dark skin pigmentation did not have good fNIRS signal quality during the experiment. Chromophore presence determines skin colour, and as fNIRS detects haemoglobin chromophore absorption, melanin may have interfered with the NIRS signals (Kwasa et al., 2023; Wassenaar & Van den Brand, 2005). Moreover, poor fNIRS signal quality occurred in participants who had thicker, curlier, and darker hair. This is because the optodes that emit light into the underlying brain matter were blocked by the type of hair (Kwasa et al., 2023). Therefore, the fNIRS results may not be reliable in these participants.

In addition, age, sex, type of yoga style practised, and the number of spoken languages should have been better accounted for in the general linear model analysis, as they can result in a confounding experiment. In this study, female participants (n=25) also outnumbered male participants (n=11), and sex differences, particularly in oestrogen levels, have been known to influence cerebral blood flow (Peltonen et al., 2015; Peltonen et al., 2016). Given the small sample, resulting in diminished statistical power in the current study, a power analysis needed to be conducted to determine the minimum number of participants required in this fNIRS study.

Most participants were sourced via convenience sampling, which does not lead to an appropriate representation of a sample of the population (Etikan et al., 2016). As it pertains to my study, the control group was sourced from a university population which consisted of lecturers and students with high levels of tertiary education, therefore, there is an overrepresentation of participants with tertiary level education, resulting in a somewhat homogenous sample which is a bias (Etikan et al., 2016). According to tertiary education statistics, published in 2019, only 7% of the adult population has tertiary education in South Africa (Organisation for Economic Cooperation and Development [OECD], 2019). Thus, the yoga and control group are not representative of South Africa's population and may thus contain a few outliers. Therefore, it is theorised that if the control group was randomly selected there would possibly be larger variances in SCWT performance between the experimental and control group. However, although the bias remains, convenience sampling is an efficient and trouble-free process (Etikan et al., 2016), particularly for data collection completed within a short time frame.

Future research can address the above limitations by ensuring that an RCT (with a yoga intervention) instead of an NRCT is used and recruiting participants who are matched for age, sex, education, yoga style, and the number of spoken languages. Moreover, future research should investigate whether oestrogen levels in females could improve cognitive functioning when compared to males, and to compare yoga-experienced females and males to each other. A larger sample size should be included to improve statistical power and improve the study's generalisation across South Africa and the globe. Future research would also benefit by comparing different yoga styles to determine which is better for cognitive functioning and if such differences exist between them.

In line with the above, future demographic questionnaires should seek to account for how physically active participants are, besides partaking in yoga exercises. Similarly, studies should ascertain whether participants are colour-blind or whether they present with visual problems that may affect completing a colour-based task such as the one used in my study. In terms of instrumentation, it is recommended that an fNIRS device with more short-channel separations would yield results that contain more validity than the fNIRS used in this study. Similarly, regarding instrumentation, future studies should source and use a research venue that is darkly lit to ensure optimal fNIRS signalling.

Chapter 6. Conclusion

In conclusion, this study indicates that although there were insignificant differences in individual and group fNIRS analyses, as well as SCWT reaction time, there was a significant difference in incongruent response accuracy between the yoga and control group. However, it is difficult to determine whether the yoga group performed better due to neuroplastic changes in the brain. This study replicates previous research regarding enhanced response accuracy in yoga groups (Eyre et al., 2017; Nilsoge et al., 2016; Phansikar et al., 2023, Telles et al., 2013).

The strengths of this study included contributing to the literature on sustained attention and experimental neuropsychology, as well as including a South African sample. Only 2% of global research consists of African-led research set in Africa, therefore South Africans are underrepresented in the global literature (Kasprowicz et al., 2020). Thus, this study addresses the lack of South African populations in research studies. Difficulties encountered in this research project were that on arrival in Makhanda, the yoga classes at Rhodes University were cancelled, which meant that the researcher had to find participants at privately owned yoga studios. Makhanda is a small city and there are not many people who practice yoga, therefore participant recruitment was very difficult.

To conclude, to the best of the researcher's knowledge, this is the first study in the South African context investigating the effects of yoga on sustained attention, using fNIRS. The significance of this study entails that sustained attention is a crucial aspect of cognitive functioning and it has profound effects on mental health (Isbell et al., 2018). Sustained attention is vital, as it serves as a foundation for the other forms of attention, as it plays a significant role in executive and overall cognitive functioning (Kokoç et al., 2021). The present research, therefore, contributes to a growing body of evidence suggesting that yoga practice has the potential to improve sustained attention as seen through improved performance on incongruent response accuracy in the SCWT.

It is envisaged that this study would contribute to the development of neuroscience and experimental neuropsychology in the domain of executive functions, sustained attention, and alternative exercise science. Yoga is a cost-effective and accessible form of alternative exercise which can support psychological functioning and cognition. This study's findings hoped to aid in the creation of interventions aiming to improve sustained attention in healthy, clinical, and neurological populations, as well as contribute to the dearth of experimental neuropsychology research in South Africa and the African continent at large.

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Appendices

Appendix A:

JOIN A RESEARCH EXPERIMENT

RHODES UNIVERSITY
Where leaders learn

Are you 18 years and older?

Yes

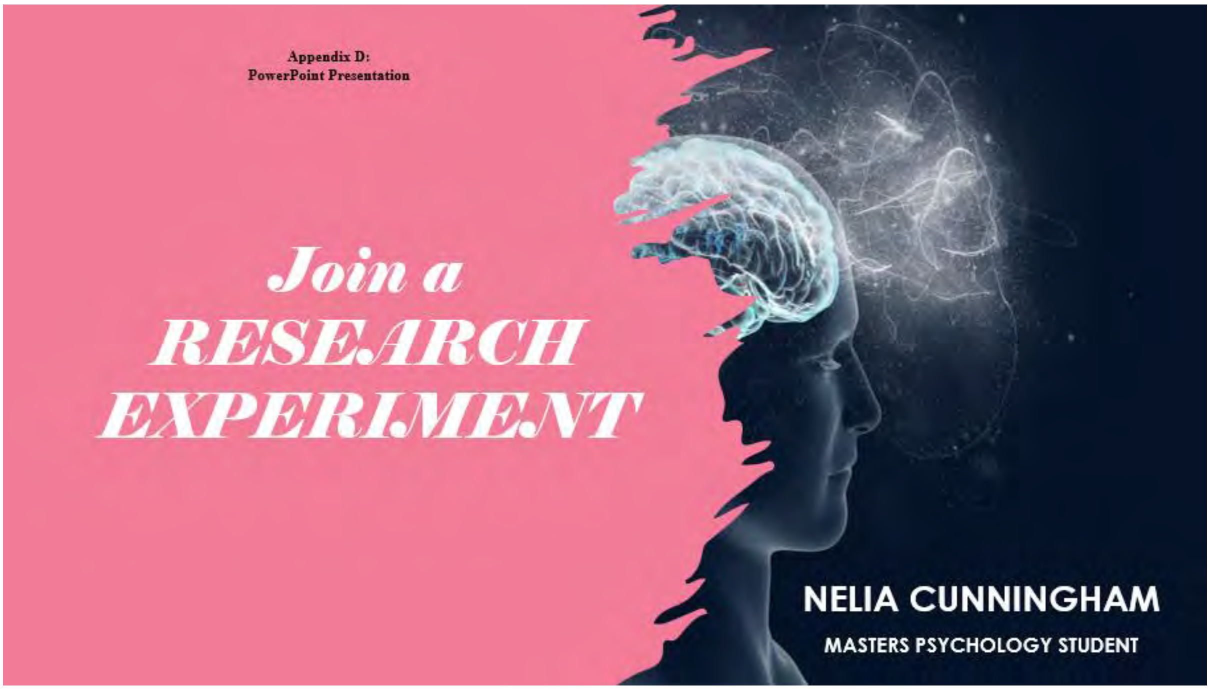
Join a research project focusing on attention and neuroimaging.

This experiment is 45 minutes.
Closes on 26 August 2022.

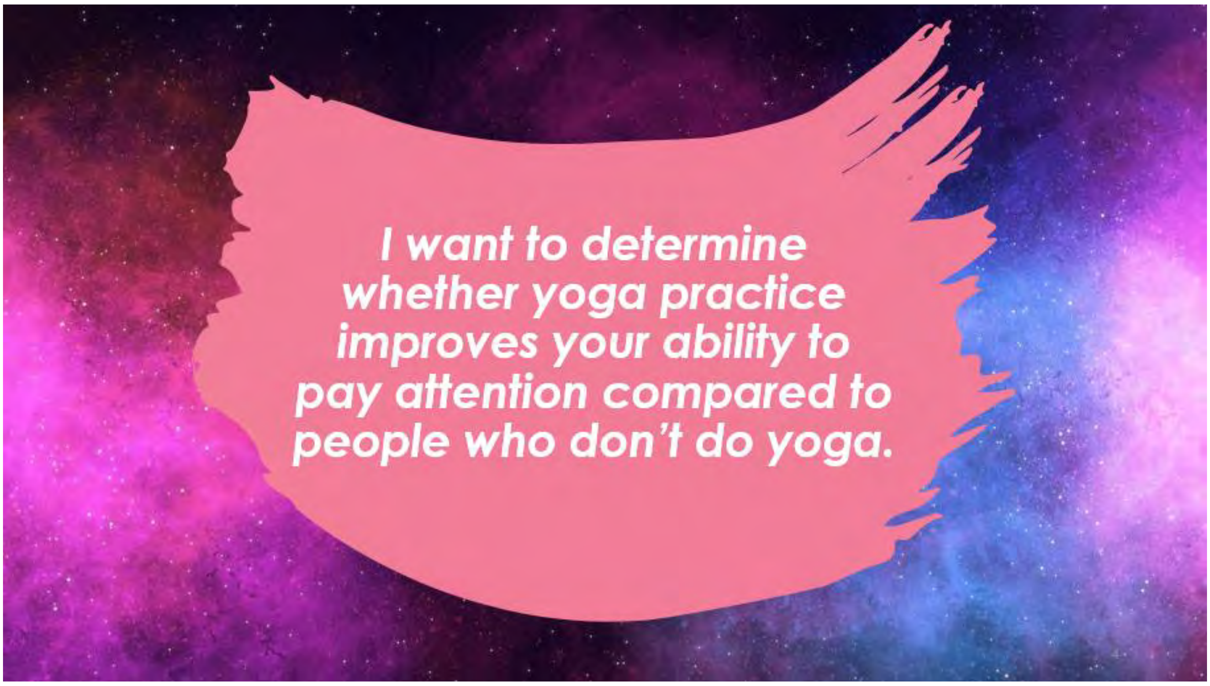
Contact Nelia for more information:
cunning.nelly@gmail.com
076 635 5771
(Masters Student)

Appendix B:

PowerPoint Presentation




JOIN A RESEARCH EXPERIMENT
RHODES UNIVERSITY
Do you practice yoga?
Yes
Are you 18 years and older?
Yes!
Join a research project focusing on attention and neuroimaging.
This experiment is 45 minutes.
Closes on 26 August 2022.
Contact Nelia for more information:
cunning.nelly@gmail.com
076 635 5771
(Masters Student)
RESEARCH POSTERS
JOIN A RESEARCH EXPERIMENT
RHODES UNIVERSITY
Are you 18 years and older?
Yes
Join a research project focusing on attention and neuroimaging.
This experiment is 45 minutes.
Closes on 26 August 2022.
Contact Nelia for more information:
cunning.nelly@gmail.com
076 635 5771
(Masters Student)


I want to determine whether yoga practice improves your ability to pay attention compared to people who don't do yoga.


Neuroimaging
Tool
FUNCTIONAL NEAR-INFRARED SPECTROSCOPY
(FNIRS)


Who can
participate?
1. Anyone older than 18
2. Anyone of any gender
3. People who practice
yoga
4. And people who don't
practice yoga

Some Details

How Long?

Less than 45 minutes.

Where?

Research room in psychology department at Rhodes University.

When?

12 August – 1 September 2022

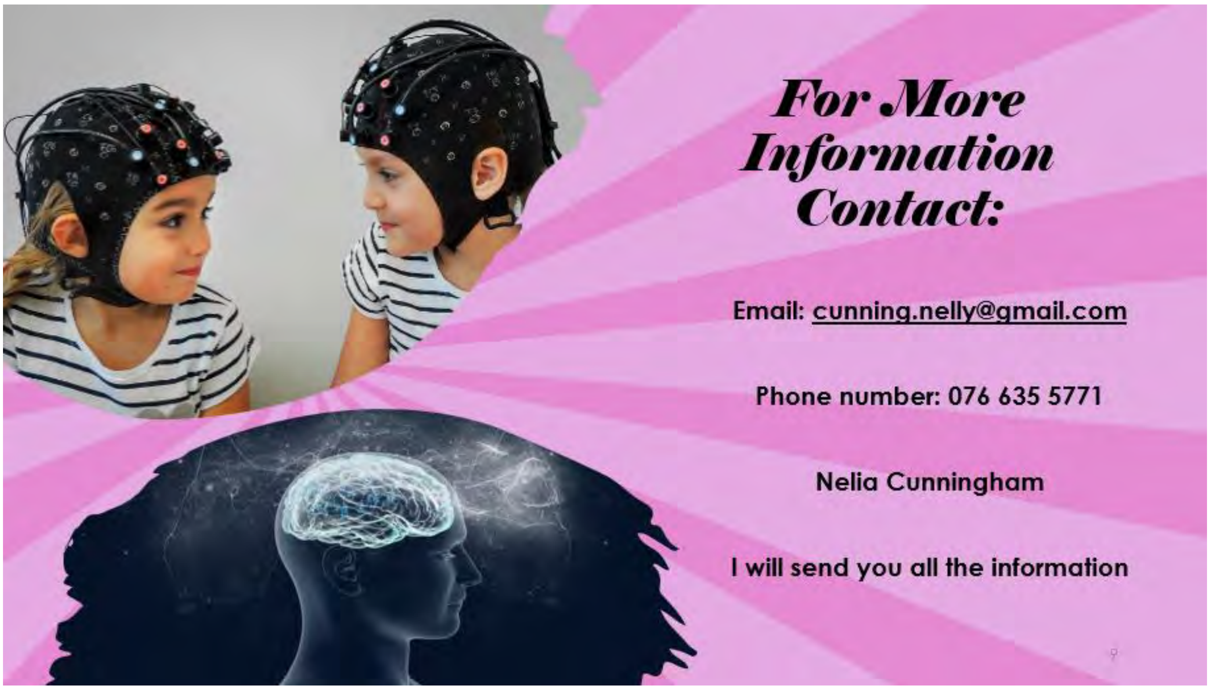
We can organise a time that suits you.

What do I do?

Sit in front of a computer with fNIRS on your head.

Complete the task that assesses your attention.

7


For More Information Contact:
Email: cunning.nelly@gmail.com
Phone number: 076 635 5771
Nelia Cunningham
I will send you all the information

Appendix C:

Demographic Questionnaire

Page 1

Demographic Questionnaire

Please complete the survey below.

Thank you!

Date

____

First Name

____

Last Name

____

Email

____

Contact Number

____

Date of Birth

____

Age

____

Biological Sex	○ Female ○ Male
Race	○ Black African ○ White ○ Colored ○ Asian/Indian ○ Other
Please specify	

Height (cm)

____

Weight (kgs)

____

02-12-2022 08:45 projectredcap.org REDCap

BMI

Highest Level of Education

- ○ High School
- ○ Undergraduate
- ○ Honours
- ○ Masters
- ○ PhD
- ○ Other

Please Specify

Home Language

- ○ English
- ○ Afrikaans
- ○ Xhosa
- ○ Zulu
- ○ Southern Sotho
- ○ Tswana
- ○ Tsonga
- ○ Venda
- ○ Ndebele
- ○ Swati
- ○ Sotho
- ○ Other

Please Specify

Other Languages Spoken
(Please list any other languages spoken below. If not applicable, respond 'N/A'.)

Handedness
(Please indicate dominant writing hand.)

- ○ Left
- ○ Right
- ○ Ambidextrous

History of Traumatic Brain Injury
(Please answer 'Yes' ONLY if you have been unconscious for >30 minutes.)

- ○ Yes
- ○ No

Please elaborate

____

Diagnosis of Neurological Disorder
(Please answer 'Yes' if you have been diagnosed with a disease that effects the nerves, brain, or spinal cord.)

◯ Yes
◯ No

Please elaborate

____

Diagnosis of Neuropsychiatric Disorder
(Please indicate whether you have been diagnosed with any of the disorders mentioned above. Select all that apply. If not applicable, respond 'N/A'.)

☐ Attention Deficit Disorder
☐ Learning Disorder (Dyslexia, Dyscalculia, Dysgraphia)
☐ Generalised Anxiety Disorder
☐ Major Depressive Disorder
☐ Persistent Depressive Disorder (Dysthymia)
☐ Premenstrual Dysphoric Disorder
☐ Bipolar I
☐ Bipolar II
☐ Schizophrenia
☐ N/A

Psychotropic Medication
(Do you take any medication to alter your mood, behaviour, or to help you sleep?)

◯ Yes
◯ No

Please elaborate

____

Herbal Medication
(Do you take any herbal medication to alter your mood, behaviour, or to help you sleep?)

◯ Yes
◯ No

Please elaborate

____

Current Mood

○ Happy ○ Excited ○ Anxious ○ Irritable ○ Depressed ○ Frustrated

Diet

○ Omnivore
○ Vegetarian
○ Vegan
○ Flexitarian
○ Other

Daily Intake of Fruit and Vegetables

What do you typically eat for breakfast?

What do you typically eat for lunch?

What do you typically eat for dinner?

How many hours do you sleep a night?

○ 0-4 hours
○ 5-6 hours
○ 7-8 hours
○ 9-10 hours
○ >11 hours

Do you suffer from insomnia?
(Please indicate whether you suffer from periods of insomnia (24 hours without sleeping))

○ Yes
○ No

Please elaborate

Do you smoke cigarettes on a daily basis?

- ○ Yes
- ○ No

Are you currently pregnant?

- ○ Yes
- ○ No

How long is your menstrual cycle?

- ○ Less than 28 days on average
- ○ 28-29 days on average
- ○ More than 29 days on average
- ○ N/A

Last menstrual period

- ○ 1 week ago
- ○ 2 weeks ago
- ○ 3 weeks ago
- ○ >4 weeks ago
- ○ N/A

Average length of menstruation

- ○ 1-2 days
- ○ 3-5 days
- ○ 5-7 days
- ○ 8 days
- ○ >8 days
- ○ N/A

Do you take hormonal birth control?
(Please indicate whether you have taken birth control within the last 3 months.)

- ○ Yes
- ○ No

Please specify
(Please indicate whether you have taken birth control within the last 3 months.)

- ○ The pill
- ○ The patch
- ○ Skin implant
- ○ Hormonal intrauterine device

Do you have any experience with meditation?

- ○ Yes
- ○ No

Please specify
(Please indicate (1) how frequently, and (2) duration of practice.)

Have you practiced meditation in the last three weeks?

- ◯ Yes
- ◯ No

Do you have any experience with yoga?
(Please indicate if you have ever tried yoga before.)

- ◯ Yes
- ◯ No

How long have you been practicing yoga?

- ◯ A number of weeks
- ◯ A number of months
- ◯ A number of years

How many times a week do you practice yoga?

- ◯ once a week
- ◯ 2-3 times a week
- ◯ 4-5 times a week
- ◯ 5 or more times a week

Have you practiced yoga in the last two months?

- ◯ Yes
- ◯ No

What is your preferred style of yoga?
(Please select yoga practice(s) that apply.)

- ☐ Hatha yoga
- ☐ Vinyasa yoga
- ☐ Iyengar yoga
- ☐ Ashtanga yoga
- ☐ Yin yoga
- ☐ Restorative yoga
- ☐ Prenatal yoga
- ☐ Anusara yoga
- ☐ Bikram yoga
- ☐ Kundalini yoga
- ☐ Jivamukuti yoga
- ☐ Other

Which style of yoga do you practice the most frequently?

- ◯ Hatha yoga
- ◯ Vinyasa yoga
- ◯ Iyengar yoga
- ◯ Ashtanga yoga
- ◯ Yin yoga
- ◯ Restorative yoga
- ◯ Prenatal yoga
- ◯ Anusara yoga
- ◯ Bikram yoga
- ◯ Kundalini yoga
- ◯ Jivamukuti yoga
- ◯ Other

Appendix D:

Ethical Clearance Letter

RHODES UNIVERSITY
Where leaders learn

Rhodes University Human Research Ethics Committee
PO Box 94, Makhanda, 6140, South Africa
t: +27 (0) 46 603 7727
f: +27 (0) 46 603 8822
e: ethics-committee@ru.ac.za
NHREC Registration number: RC-241114-045

https://www.ru.ac.za/researchgateway/ethics/

21 June 2022

Cornelia Cunningham

Email: g20c6447@campus.ru.ac.za

Review Reference: 2022-5505-6841

Dear Cornelia Cunningham

Title: To Yoga or not to Yoga? The Effect of Yoga on Sustained Attention: An fNIRS study

Researcher: Ms Cornelia Cunningham

Supervisors: Mr Sizwe Zondo

This letter confirms that the above research proposal has been reviewed and **APPROVED** by the Rhodes University Human Research Ethics Committee (RU-HREC). Your Approval number is: 2022-5505-6841

Approval has been granted for 1 year. An annual progress report will be required in order to renew approval for an additional period. You will receive an email notifying you when the annual report is due.

Please ensure that the ethical standards committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the ethics committee on the completion of the research. The purpose of this report is to indicate whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloguing number allocated.

Sincerely,

Arthur Webb

Prof Arthur Webb

Chair: Rhodes University Human Research Ethics Committee, RU-HREC

cc: Ms Danielle de Vos - Ethics Coordinator

Appendix E:

Email for the Student Mailing List

Subject: PAY ATTENTION! Invitation to participate in a research project focusing on 'attention'.

Dear students,

My name is Nelia Cunningham, I am a Master's student from the Department of Psychology at Rhodes University, and I am inviting you to take part in my Master's Research Project.

Have you ever wanted to find a natural way that could potentially improve your ability to pay attention? Or to improve your academic performance? Or to prevent early cognitive decline? Well, you have come to the right place!

My research is a locally based project, and it aims to investigate whether yoga affects attention, as measured by a neuro-imaging technique called functional near-infrared spectroscopy (fNIRS). This research has received ethical clearance from Rhodes University (Reference number: 2022-5505-6841).

You are eligible to participate in this study if you are (1) between the ages of 18 – 55 years and (2) practice yoga. You are also eligible if you have never done yoga before, but also if you have practised yoga before (at least 4 weeks within the last 2 months).

If you agree to participate in this project, please contact me at my email address: cunning.nelly@gmail.com stating that you would potentially like to join, and I will email all the necessary documents and information to you, which will take about 25 – 35 minutes to read and complete.

If you have any questions about this study, please feel free to email the researchers: cunning.nelly@gmail.com or s.zondo@ru.ac.za or victoria.williams@wits.ac.za

This research will run until 31 August 2022.

Thank you.

Appendix F:

Participant Information Sheet

Dear Participants,

Welcome to my research project! My name is Nelia Cunningham, I am a master's student at the Department of Psychology at Rhodes University. For my research, I am interested in investigating the extent to which yoga influences attention. Two groups will be compared: (1) a yoga group ('experimental group'), and (2) a non-yoga group ('control group') on how they perform during a computerised task which assesses attention, which will be monitored through a neuroimaging tool called functional near-infrared spectroscopy (fNIRS). The tool is used to analyse brain hemodynamic responses. To the best of my knowledge, this will be the first experimental research project focusing on attention and yoga as monitored by the neuroimaging tool, fNIRS, in South Africa.

1. Who can participate in this study?

My inclusion criteria are the following:

1. Women and men.

2. 18 years and older.

3. (a) If you practice yoga, or (b) If you do not practice yoga.

Unfortunately, if you have a history of any neurological diseases i.e., strokes, concussions that lasted for more than 30 minutes, epilepsy, and traumatic brain injury, you will not be liable to participate in this study.

2. What is the process involved?

The entire research procedure is a once-off and will only take 45 minutes. There are three steps involved:

<u>Step One</u>

The first part of the experiment is approximately 10 - 15 minutes in duration. This can be completed at home and at a time that is convenient for you. You are required to read and complete the following documents: (1) the participant information sheet, (2) the fNIRS information sheet, (3) the informed consent form and (4) the demographic questionnaire (link).

When you have finished, please email the signed informed consent form to me (cunning.nelly@gmail.com). Thereafter, we can set a date and time for the experiment.

Step Two (optional)

We can arrange a video call meeting on WhatsApp or Zoom to clarify any concerns or questions that you may have regarding the experiment.

Step Three

You will be required to come to the entrance of the Psychology Department at Rhodes University, where we will meet. The experiment will take place in a research room inside the Psychology Department. Here, you will: (1) complete a 45-minute computerised task that assesses attention, and while you are doing this, the neuroimaging tool (fNIRS) will be placed on your head to monitor brain activity. Once the task has finished, you have officially completed the experiment and are free to leave. When my research has been published, I will email the link to you so that you can see the outcome of this experiment that you took part in.

3.COVID-19 health and safety protocols in the research room.

Covid-19 is still part of our lives and thus appropriate health and safety protocols will be implemented to reduce the risks involved, and this includes:

3.1. Health screening of participants and researchers involved in the study:

• If you are considered a 'high-risk candidate', it is advised that you consult with your doctor before taking part in this study.

• Upon entering the research room, a Covid-19 screening questionnaire will be completed. If you answer 'yes' to any of the questions regarding Covid-19, you will not be allowed to enter at this time, but you will have an opportunity to participate at another time.

• Optional: your hands will be disinfected with a 70% alcohol-based hand sanitiser.

3.2. Daily logbook:

• The date, participant name, contact details, and time of arrival will all be recorded in a logbook for contact tracing purposes.

3.3. Precautionary measures in the research room in the Psychology Department

• The room will be disinfected in-between participants with sanitiser.

• There will only be one participant scheduled in the research room (in the psychology department) at a time.

• Facemasks are optional.

• All pens will be disinfected before and after use.

4. Risks Associated with this research:

fNIRS Cap: fNIRS is considered a safe, non-invasive neuroimaging method. The researcher will also ensure that the fNIRS cap is comfortably placed upon your head to prevent any potential discomfort. There is a risk that the fNIRS cap might be uncomfortable for some participants.

Covid-19: Precautionary measures will be taken to minimise risks of infection.

Incidental findings from fNIRS neuroimaging: An incidental finding is an unexpected finding that the participant is oblivious to, which is unrelated to the current research, but which may be deemed important regarding cognition, or health. There is a 3-12% chance that a finding like this might occur during the fNIRS recording. If any unexpected finding is found during the fNIRS recording, the researcher will discuss this with her supervisors, as the researcher is not a qualified professional on these matters and is therefore unable to judge this appropriately. The fNIRS is not searching for a diagnosis as it is merely involved in research, therefore there is a likelihood of false positives and false negatives. However, participants need to be aware of the likelihood of an unexpected finding. As a participant, you have a choice on whether to give your consent if you would like to know if anything serious or potentially life-threatening was found during the fNIRS recording and to give your consent for your fNIRS data to be sent to a professional in neuropsychology or neurology for it to be professionally assessed. If the results from the professional come back with a verified and serious life-threatening disease, the participant will be informed and referred for a formal medical assessment.

5. Benefits of participation

There are no direct benefits associated with participating in this study. However, the results obtained from this study will contribute to experimental and neuroimaging research in South Africa and the African continent at large. When the research project is completed, an email with the link will be sent to you so that they can have access to the research findings related to the study.

6. Confidentiality and Anonymity

The researcher is committed to your privacy. Your data will not be made available to the public without your consent. In this instance, your personal information will have a unique number coding to make sure you cannot be identified and that you remain anonymous throughout the research. The data generated from this study will be locked in a password-protected safe that is only accessible to the researchers associated with the study.

7. Withdrawal from this Study

Participation is entirely voluntary, and you can withdraw from this study at any time. If you choose to withdraw, the data collected will be discarded, and not included for data analysis purposes. Please note that you will not be penalised in any way should you wish to withdraw from the study.

8. Research Outputs

Once the research project is completed, the researcher will present the research findings ether at a conference, or in the form of a publication. At your request, a link will be emailed to you so you can have access to the research findings.

9. Contact details of the chairperson of the Research Ethics Board

Please contact the Rhodes University Ethics Committee if you have any questions about the integrity of the ethics of this study. Contact person: Dr Arthur Webb (a.webb@ru.ac.za).

10. Contact Details of the primary researcher

Please contact me directly if you have any questions about the research: Nelia Cunningham (cunning.nelly@gmail.com), 076 635 5771.

11. Contact details of my supervisors

If you have any questions regarding the research that you would like to take up with my supervisors, please contact Mr Sizwe Zondo (s.zondo@ru.ac.za) and Dr Victoria Williams (victoria.williams@wits.ac.za).

Thank you taking time to read this Information Sheet, and if you are interested in participating in the study, please email me, Nelia Cunningham on the above email address and attach the completed signed documents (participant information sheet, fNIRS information sheet, demographic questionnaire, and informed consent form). Your participation will be highly appreciated.

Appendix G:

Participant fNIRS Information Sheet

Dear Participants,

The below sheet provides information on the neuroimaging tool, functional near-infrared spectroscopy (fNIRS). Research Project: To yoga or not to yoga? An fNIRS experimental study on the effects of yoga on attention.

1. What is fNIRS?

Functional near-infrared spectroscopy (fNIRS) is a neuroimaging tool that is used to monitor hemodynamic changes in the brain. It operates by shining NIR (near-infrared) light through the skull via surface electrodes placed on the scalp, where they shine NIR light into the brain's underlying tissue (Pinti et al., 2020). fNIRS NIR light is safe, non-ionizing and does not contain radiation. The amount of light that enters the brain is the same amount as sunshine on a sunny day when you are outside. This light shines roughly 1.5 to 2.5 cm below the skull, where some of this light is absorbed by chromophores, where haemoglobin (red blood cells that transport oxygen throughout the body) is the primary chromophore that absorbs the NIR light (León-Carrión, & León-Domínguez, 2012). fNIRS measures oxygenated haemoglobin, deoxygenated haemoglobin, and total haemoglobin in the brain, where an increase in oxygenated haemoglobin and a decrease in deoxygenated haemoglobin, are associated with increased brain activity (León-Carrión, & León-Domínguez, 2012).

2. How do I prepare for the fNIRS recording?

Before the commencement of the experiment, it is advised that the following steps are taken:
(1) Wash your hair the night before the fNIRS recording.

(2) Please bring your spectacles or contact lenses if needed.

(3) Ensure that you are well-rested, as this will prevent mental fatigue.

(4) Wash your hair after the experiment is completed.

3. What can I expect on the day of the Experiment/fNIRS recording?

The entire research experiment includes an fNIRS recording and a computerised attention task which occurs at the same time. The entire experiment will take less than 45 minutes. Below are the following steps:

1. You will undergo a Covid-19 screening.

2. Your current emotional mood will be asked.

3. You will become familiarised with the fNIRS neuroimaging tool.

4. You will be asked to sit in front of a computer, while the fNIRS cap is securely fitted onto your head. Please note, that if you are uncomfortable with someone touching your head and chin, it is advised that you refrain from taking part in this experiment.

5. You will receive instructions for the cognitive task, and you will have time to ask questions.

6. The computerised attention task will start and will take less than 45 minutes to complete.

7. Once the cognitive task and fNIRS recording are complete, the imaging cap will be carefully removed from your head.

8. The experiment is finished.

4. What are the risks involved?

The fNIRS neuroimaging tool, including the protocols followed for set-up and recording, has been extensively used in clinical and academic research. It is considered a very safe, and non-invasive neuroimaging tool that uses non-ionizing light to monitor brain activity. It is used across a range of populations from infants to the elderly. To date, no side effects have been reported on the use of the instrument.

There is a risk that some might find the fNIRS cap uncomfortable. You will be fitted with the correct fitting fNIRS cap during the experiment.

There is a low chance that an unexpected finding may or may not be found. An unexpected finding is something that is not related to the research project but could be important regarding the participant's health.

Kind regards,

Miss Nelia Cunningham

For more information on fNIRS please consult the following:

https://nirx.net/

https://openfnirs.org/

León-Carrión, J., & León-Domínguez, U. (2012). Functional near-infrared spectroscopy (fNIRS): principles and neuroscientific applications. Neuroimaging methods, 48-74.

Pinti, P., Tachtsidis, I., Hamilton, A., Hirsch, J., Aichelburg, C., Gilbert, S., & Burgess, P. W. (2020). The present and future use of functional near-infrared spectroscopy (fNIRS) for cognitive neuroscience. Annals of the New York Academy of Sciences, 1464(1), 5-29. doi: 10.1111/nyas.13948

Appendix H:

Informed Consent Form

PARTICIPANT INFORMED CONSENT DECLARATION

(To be signed by research participants)

Research Project Title: To Yoga or Not to Yoga? The Effect of Yoga on Sustained Attention: an fNIRS study.

I, Nelia Cunningham from the Department of Psychology, Rhodes University, have requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project and this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to investigate whether yoga affects sustained attention, as monitored by a neuroimaging technique called functional near-infrared spectroscopy (fNIRS).

2. Rhodes University has given ethical clearance to this research project. The ethics reference number is **2022-5505-6841**. I have seen/may request to see the clearance certificate by contacting the Ethics Coordinator (ethics-committee@ru.ac.za).

3. By participating in this research project, I will be contributing to research and information regarding cognition, and the neuronal architecture surrounding cognition.

4. I will be participating in the research project by having the fNIRS placed on my head while I complete a 45-minute on a computerized task that assesses attention. The fNIRS will measure the changes in oxygenated haemoglobin, deoxygenated haemoglobin and total haemoglobin in my brain.

5. My participation is entirely voluntary and should I at any stage, wish to withdraw from the study, I may do so without any negative consequences.

6. I will not be compensated for participating in the research.

7. The following risks are associated with my participation: possible Covid-19 infection and slight discomfort whilst fitting the fNIRS cap.

8. The Researcher intends to publish the research results in the form of a research article. However, confidentiality and anonymity of records will be maintained, and my name and identity will not be revealed to anyone who has not been involved in researching unless I indicate to the contrary/recognise that as a public figure, my identity will inevitably be/become known in which case I agree to and accept the loss of confidentiality.

9. In terms of the Protection of Personal Information Act (No. 4, 2013), it remains my right to request the Researcher to provide me with a detailed explanation of exactly how confidentiality and anonymity will be achieved. I may request to know how my personal information will be stored securely, and for how long it will be stored.

10. I am aware that the data collected for this study will not be used by the researcher for another research project.

11. In terms of the Protection of Personal Information Act, I possess the right to receive feedback about this research. This will take the form of a link for access to the published article unless I elect not to receive feedback.

12. Any further questions that I might have regarding the research or my participation will be answered by the researcher, Cornelia Cunningham, at cunning.nelly@gmail.com or g20c6447@campus.ru.ac.za, or her supervisors; Mr Sizwe Zondo s.zondo@ru.ac.za and Dr Victoria Williams victoria.williams@wits.ac.za

13. By signing this informed consent declaration, I am not waiving any legal claims, rights or remedies.

14. I am aware that no photographs will be taken of me.

15. I am aware that my voice will not be recorded.

16. A copy of this signed informed consent declaration will be given to me, and the original will be kept on record by the researcher.

17. I understand that the fNIRS recording requires the placement of surface electrodes on my scalp, used to measure hemodynamic responses in the brain.

18. I understand that the fNIRS cap or sensors can be removed at any time if I so desire.

19. I acknowledge that there are minimal risks involved in this procedure, such as an unexpected incidental finding, or that the fNIRS cap may be uncomfortable.

20. I have read through the fNIRS and participant information sheet, and my questions have been answered to my satisfaction.

I, ……………………………………………………………………………, have read the above information / confirm that the above information has been explained to me in a language that I understand, and I am aware of this document's contents. I have asked all the questions that I wished to ask, and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurized in any way and I voluntarily agree to participate in the above-mentioned project.

……………………………………… ………………………………..

Participant's signature **Date**

Appendix I:

Covid-19 Screening/Logbook

RHODES UNIVERSITY
Where leaders learn

COVID-19 DAILY SELF-ASSESSMENT SCREENING QUESTIONNAIRE

(to be handed in at the access point and/or completed at the access point)

- **If you answer YES to any of the symptom questions you will not be permitted to partake in the study.**
- **If you have not completed the Assessment and Orientation, you are not permitted to partake in the study.**

Name of Staff / Student Member / Visitor	
Identity number of staff /student member / Visitor	
Staff number (staff only) or Student number (students only)	
Company (visitors)	
Purpose of Visit (visitors)	

Capacity of visitor to Campus: (please tick here)

Staff member:

- Academic ☐
- Support ☐

Student: ☐

Visitor: ☐
(Provide full details in the left-hand column)

Do you have any of the following symptoms?		
Fever (high temperature)	Yes	No
Cough	Yes	No
Sore throat	Yes	No
Shortness of breath	Yes	No
Myalgia (general weakness)	Yes	No
Loss of taste (ageusia)	Yes	No
Loss of sense of smell (anosmia)	Yes	No
Body aches	Yes	No
Redness of the eyes	Yes	No
Nausea/vomiting/diarrhoea	Yes	No
Risk Assessment and Orientation?		
Have you done the Initial Risk Assessment at the Health Care Centre?	Yes	No
Have you done the training and/or watched the training video online?	Yes	No
Exposure to someone with Covid-19?		
Have you been in contact with someone who has tested positive for COVID-19 in the past 14 days?	Yes	No
Declaration:		

I hereby certify that the information I have provided in this form is complete, true and accurate and I give permission for the University to validate any information provided.	
In line with the Protection of Personal Information Act, you are required to give permission for the University to check the accuracy of any information provided. Should it become apparent that the information you have provided is false our disciplinary procedures and processes will apply. In the case of visitors, you will not be permitted to enter the campus in the future and your company will be advised.	
Signature	
Date	

Updated version: May 2021

Appendix J:

Research Checklist

Participant Number & Name ………………………………………………………………….

fNIRS working and battery life

Informed Consent obtained:

Covid-19 Screening done:

Notes:

Sleep well? Yes No

Sick? Yes No

Current mood: positive, neutral, negative.

Yoga instructor? Yes No

Explain Stroop Test

Do Stroop practice round(s) on paper

Explain fNIRS

Measure Head circumference cm

Measure Distance from Inion and nasion fz point cm

With Red marker indicate two fingers width from orbits

Ensure optodes facing the same direction

Tie loose sources

Dim lights

Check channels

Run fNIRS and Stroop test twice.

Type name in: Name_2022_month_day_Yoga_fnirs_stroop

(start ST – start recording – strop ST – stop recording, save data under *name task 1*, start ST – start recording – stop ST – stop recording, save under *name task 2).*

Save data

Appendix K:

Participant Experiment Instructions

‘The assessment that you will be doing is the Stroop Test. It is a psychological test that assesses various cognitive functions including working memory, inhibition, and attention. This is the fNIRS neuroimaging tool. It works by shining light into your brain through a source (show participant the source) where this light travels into your brain, then it makes a banana-shaped curve, and the light goes to the detector (show participant the detector then place the fNIRS on the participant's head). Before you start, please ensure that the fNIRS cap is positioned comfortably on your head (if not I’ll adjust it accordingly) and ensure that you are sitting in a comfortable position with both of your index fingers on ‘Q’ and ‘P’.

In this task, you need to see whether the colours of the ink of the top word, match the meaning of the bottom word. If so, press ‘Q’, however if not press ‘P’. There will be 10 practice rounds, thereafter the real task will commence. Sometimes an ’X’ will appear on the screen and that is a resting period. When you see it just stare at it. Please note, you are allowed to leave the assessment at any time if you do not want to continue anymore, and this will not be held against you in any way.

Alright, are you ready? Great, when I say ‘start’, you can press the ‘space bar’ in the middle of the keyboard and start with the task. It will automatically come to an end after 7 minutes, thereafter we will do it for a second time to save the data in case it is corrupted. Good luck.’

Appendix L:

Decontaminating the fNIRS Cap (for Laboratory Research Assistants / MA & PhDs)

The fNIRS cap will be disinfected before and after it is placed on each participant to prevent the spread of Covid-19 (a lipid-enveloped virus) and other viruses or bacteria (EASYCAP, 2022). FNIRS equipment becomes brittle after each decontamination procedure, especially if it is disinfected with 70% alcohol as the corrosive elements result in the electrodes becoming inoperative, therefore the following guidelines will ensure the longevity of the fNIRS equipment and best practices to prevent the spread of viruses for the participant and researcher (EASYCAP, 2022).

As a researcher, I will follow the below *Care, Handling and Safe Use Instructions* / guidelines for the fNIRS disinfecting procedures.

- Use a disinfectant with less than 20% ethanol to clean the cap.
- The fibre optical probes are very sensitive, therefore only the parts that were in contact with the skin will be wiped with paper tissue in diluted isopropyl alcohol at 70%.
- Surgical gloves will be worn over sanitised hands (70% alcohol) when placing the fNIRS cap on participants to prevent any contamination with bodily fluids.
- Probes and short-distance detectors will be removed from the cap before the cap is soaked in minimal disinfectant for the minimum required soaking time.
- I will use aldehyde-based disinfectants to clear the fNIRS cape during washing.
- FNIRS cap will be rinsed thoroughly with water after washing/ disinfection.
- After rinsing, the fNIRS cap will be left to dry in the Psychology Department's neuroimaging dry room. Dry air is a suitable disinfectant as most viruses and bacteria die after a few minutes in dry environments.

The above procedures have been adapted from:

EASYCAP. (2022). Retrieved April 25, 2022, from https://www.easycap.de/

NIRX. (2017). Retrieved April 25, 2022, from https://nirx.net/nirx-equipment-disinfection

Appendix M:

Individual fNIRS Analyses – Individual Signal Quality Display for each Participant

Yoga Participant 1

Yoga Participant 2

Yoga Participant 3

Control Participant 1

Control Participant 2

Control Participant 3

Note: The above images were captured from CortiPrism and displayed the signal quality for each participant that was included for individual analysis.

Appendix N:

Shapiro-Wilk Results

Shapiro-Wilk Results Indicate a Normal Distribution

Dependent Variable	Shapiro - Wilk		*p*-value of Shapiro-Wilk	
	Control	Yoga	Control	Yoga
S1 – D1 Congruent	0.778	0.896	0.062	0.411
S1 – D1 Incongruent	0.987	0.891	0.784	0.388
S2 – D2 Congruent	0.905	0.970	0.437	0.670
S2 – D2 Incongruent	0.914	0.987	0.490	0.780
S3 – D1 Congruent	0.970	0.955	0.897	0.649
S3 – D1 Incongruent	0.930	0.970	0.346	0.873
S3 – D2 Incongruent	0.927	0.961	0.173	0.713

Note: The above information was captured from JASP and details the channels that were normally distributed.