UNIVERSITY OF TECHNOLOGY SYDNEY

Heart rate variability and neurocognitive performance in blue- and white-collar workers:

Implications for cardiac risks

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Submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy (Science) at the University of Technology Sydney.

Declaration

I Ardalan Eslami declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy (Science), in the School of Life Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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List of Publications and Presentations

Publications

List of Publications

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Conference Abstracts

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List of Presentations

National Conferences

ESLAMI, A., LAL, S. Heart Rate Variability in NSW Teachers: an exploratory study investigating implications for cardiac risks. Poster presentation: 32nd Combined Health Science Conference; New Horizons 2015, Sydney, Australia

ESLAMI, A., LAL, S. Heart Rate Variability in NSW Teachers: an exploratory study investigating implications for cardiac risks. Poster presentation: Inter-University Neuroscience & Mental Health Conference 2016, Sydney, Australia

International Conferences

ESLAMI, A., NASSIF, N., ZASLAWSKI, C., LAL, S. HRV changes in response to working memory and attention tasks in white-collar workers. Poster presentation: 27th Annual meeting of the Australasian Society for Psychophysiology 2017, Sydney, Australia

ESLAMI, A., NASSIF, N., ZASLAWSKI, C., LAL, S. Cardiovascular changes during working memory and attention tasks: assessment of blue- and white-collar workers. Poster presentation: 58th Annual meeting of the Society for Psychophysiological Research 2018, Quebec City, Canada.

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Abbreviations

ABS = Australian Bureau of Statistics

ACTH = Adrenocorticotropic Hormone

ADHD = Attention Deficit Hyperactivity Disorder

A/D Converter = Analog to Digital Converter

Ag = Silver

Ag/Cl = Silver Chloride

AIHW = Australian Institute of Health and Welfare

ANS = Autonomic Nervous System

AST = Attention Switching Task

BMI = Body Mass Index

BP = Blood Pressure

CANTAB = Cambridge Neuropsychological Test Automated Battery

CHD = Coronary Heart Disease

CHF = Chronic Heart Failure

cm = Centimetre

CPT = Continuous Performance Task

CR = Cardiac Reactivity

CRH = Corticotropin Releasing Hormone

CV = Cardiovascular

CVD = Cardiovascular Disease

df = Degrees of Freedom

ECG = Electrocardiogram

F = F Statistic

FFT = Fast Fourier Transform

fMRI = Functional Magnetic Resonance Imaging

GHQ = General Health Questionnaire

GP = Good Performance

HF = High Frequency

HPA = Hypothalamic Pituitary-Adrenal

HR = Heart Rate

HREC = Human Research Ethics Committee

HRV = Heart Rate Variability

Hz = Hertz

IMT = Intima-Media Thickness

LF = Low Frequency

LF/HF = Low Frequency to High Frequency Ratio (sympathovagal balance)

m = Minutes

MI = Myocardial Infarction

mm = Millimetres

mmHg = Millimetres of Mercury

MMSE = Mini-Mental State Examination

MRI = Magnetic Resonance Imaging

ms = Milliseconds

ms^2 = Milliseconds Squared

mV = Millivolts

n = Sample Size

NRU = Neuroscience Research unit

p = p Value

PFC = Prefrontal Cortex

pNN50 = Percentage of NN intervals >50ms apart

PNS = Peripheral Nervous System

PP = Poor Performance

RMSSD = Root Mean Square of Successive Differences

RSA = Respiratory Sinus Arrhythmia

RVP = Rapid Visual Processing

SD = Standard Deviation

SDANN = Standard Deviation of Averaged NN Interval

SDNN = Standard Deviation of NN Interval

SSP = Spatial Span

SWM = Spatial Working Memory

t = T Statistic

TP = Total Power

U = U Statistic

UTS = University of Technology Sydney

VLF = Very Low Frequency

VWM = Verbal Working Memory

WHO = World Health Organisation

WM = Working Memory

WMS = Weschler Memory Scale

WMT = Working Memory Task

Z = Z Score

↓ = Decrease

> = Greater Than

↑ = Increase

< = Less Than

± = Plus minus

* = Regression Analysis Performed

Abstract

The 21st century has seen a significant and ever-growing focus on performance and productivity within the workforce. The literature has shown that attenuated cognitive ability is not only associated with reductions in performance but also with increased risk of cardiovascular disease as indicated by heart rate variability (HRV) (Hansen et al., 2003, Forte et al., 2019). The present research investigated the links between HRV and neurocognitive performance in blue- and white-collar workers.

Data was obtained from n = 101 participants aged between 19-61 years comprising of n = 48 white-collar workers (male: n = 25, female: n = 23) and n = 53 blue-collar workers (male: n = 42, female: n = 11). The experimental protocol commenced with three blood pressure (BP) recordings, a questionnaire battery to obtain demographic and lifestyle data, as well as to determine eligibility of inclusion into the study, and the General Health Questionnaire (GHQ 60). HRV data was obtained using a 3-lead electrocardiogram (ECG) during baseline (10 minutes) and then during multiple neurocognitive tasks designed to assess working memory and attention function. These tasks are part of the Cambridge Neuropsychological Test Automated Battery (CANTAB) and included the following tasks: the spatial working memory (SWM), attention switching task (AST), rapid visual processing (RVP), and the spatial span (SSP). Three final post-study BP recordings were obtained to complete the experiment.

Higher parasympathetic activity was significantly associated to less errors made by the white-collar workers in the SWM task ($r = -0.30$, $p = 0.04$). The blue-collar workers also showed a relationship between higher parasympathetic activity and enhanced performance, namely, superior ability to detect sequences ($r = 0.28$, $p = 0.04$) during the RVP task. Interestingly, increased parasympathetic dominance was also linked to more errors made by the white-collar workers ($r = -0.31$, $p = 0.04$) during the AST. The blue-collar workers also showed increased parasympathetic dominance was correlated to a slower reaction time ($r = -0.28$, $p = 0.048$) during the RVP task. Moreover, blue-collar workers showed lower indices of HRV.

The initial findings of the present research indicate that white-collar workers perform better on neurocognitive tasks, however, higher LF HRV ($p = 0.02$) and lower HF HRV ($p = 0.03$) in white-collar workers indicates higher susceptibility to cardiovascular disease (CVD) as compared to blue-collar workers. These preliminary findings demonstrate the importance of considering the effect of occupation on both neurocognitive performance and cardiovascular disease.

Chapter 1 Introduction

1.1 Australia's Occupational Landscape

Australia's current population is 25.5 million, of which half is employed (Australian Bureau of Statistics (ABSa), 2019). In the twenty-first century, productivity has become a crucial element in the strength and sustainability of a company's gross business performance (Koopman et al., 2002). As such, the literature continues to report on various professional aspects and their links to productivity and profit (Grifell-Tatjé and Lovell, 1999, Australian Bureau of Statistics (ABSb), 2014). Employment opportunities continue to grow in Australia with white-collar employment growth outpacing blue-collar employment (David, 2017).

Furthermore, occupations deemed as white-collar professions require a high level of neurocortical ability (Radanovic et al., 2003) and any disruptions to cognitive function can have detrimental effects on performance. It is well reported throughout the literature that employees at all levels can experience high levels of stress, which can ultimately affect performance (Park, 2007). Additionally, there are various challenges that both blue- and white-collar workers face on a daily and long term basis which may induce severe bouts of stress (Purves et al., 2004).

1.1.1 The White-Collar Employee

White-collar professions include lawyers, bankers, accountants, administrative staff, and other office workers. These professions often require a working understanding of business, technology, finance, interpersonal relationships, management and more. It is, therefore, necessary for these employees to maintain high levels of executive functioning, such as memory and attention (as discussed in Chapter 1.3 below), to effectively perform their tasks and duties.

The management and organization lie at the heart of a company or institute's performance (Augier and Teece, 2009). Thus, managers play a critical role inside organisations where they not only direct operations but also orchestrate and allocate the use of resources in order to best achieve the goals of the company (Augier and Teece, 2009).

1.1.2 The Blue-Collar Employee

Blue-collar workers are the backbone of modern Australia and are focused on jobs involving manual labour. The major blue-collar industries in Australia are construction and manufacturing, but also include, carpenters, electricians, plumbers, drivers, and more (Australian Bureau of Statistics (ABSa), 2019). More recently there has been record job growth in blue-collar industries, once dampened by developments in technology and artificial intelligence. A report on the industry (Jim, 2017) highlights that the manufacturing industry accounts for close to 1 million jobs, with $100 billion in value added, and a further $100 billion in exports. The blue-collar industries should therefore not be taken for granted or be underestimated for their contribution to the national economy.

Blue-collar employees have been shown to have higher prevalence of a large range of health complications, particularly cardiovascular disease (CVD) (Nakamura et al., 2000, Luckhaupt et al., 2014, Prihartono et al., 2018). It is well established in the literature that CVD is related to individual behaviour and lifestyle, and it is increasingly becoming understood that a populace with poor education and low income are more likely to engage in unhealthy behaviours and lifestyles (Clougherty et al., 2010). Therefore, continued work aimed at understanding the effects of the workplace on employee health is of great importance.

1.2 Cardiovascular Disease and Risk

Cardiovascular diseases (CVD) are the number one cause of deaths worldwide (World Health Organisation (WHO), 2017). The number of people living with CVD is increasing due to several factors including population ageing and advancements in technology and medicine which have resulted in increased longevity (Department of Health, 2015). Cardiovascular disease is a collective term for diseases of the heart muscle and blood vessels, which, include coronary heart diseases (CHD), peripheral vascular disease, and stroke (Department of Health, 2015). There are eight risk factors for heart disease (WHO, 2017) which include six modifiable and two non-modifiable elements. Of the six modifiable risk factors three are considered to be biological: (i) high blood pressure, (ii) diabetes, (iii) abnormal cholesterol and the remaining three to be lifestyle components: (iv) tobacco use, (v) obesity, and (vi) inactivity. The non-modifiable risk factors are known to be (vii) genetic history and (viii) age. As such, these behavioural and lifestyle practices have made this disease the largest burden on Australian society and economy (WHO, 2017).

The WHO (2017) estimates approximately 17.9 million deaths as a result of CVD, representing 31% of all deaths globally. In Australia alone, 43.5 thousand deaths were a result of CVD in 2013 (Nichols et al., 2015). Cardiovascular disease places incredible pressure on Australian society contributing to an already enormous economic burden. In 2015-16, CVD accounted for 9% ($10.4 billion) of health care expenditure and constituted the second largest disease group (Australian Institute of Health and Welfare (AIHW), 2019) (Figure 1.1). CVD has therefore been one of the major causes of death and disease in Australia for a long period of time (AIHW 2019). Moreover, a staggering $1.6 billion was spent on cardiovascular system medicines through the pharmaceutical benefits scheme alone in 2013-2014 (Nichols et al., 2015). Additionally, in 2010, the total economic cost of solely coronary heart disease was $18.3 billion (Deloitte Access Economics, 2011). This is set to escalate with increasing life expectancy, increasing obesity and diabetes (Deloitte Access Economics, 2011).

Figure 1.1 Healthcare Expenditure by Disease Group in Australia, 2015-16

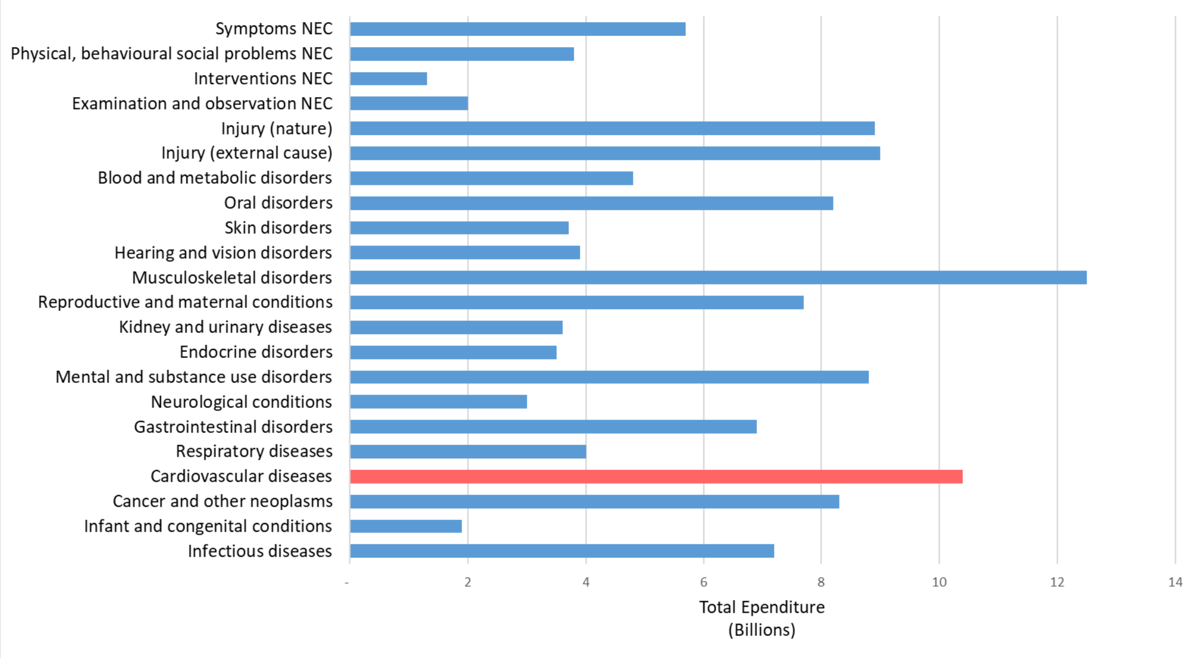


Figure 1.1 The major disease groups with respect to the allocated healthcare expenditure in 2015-16 are shown. Cardiovascular diseases ranked the second highest after musculoskeletal disorders. Image created from Australian Institute of Health and Welfare (AIHW) 2019 data.

1.2.1 Cardiovascular Risk and Occupational Health

The workplace can often play a major role in the onset of cardiovascular disease. Current European guidelines on the prevention of CVD recommend an assessment of long-term stress, which includes occupational stressors and social isolation determined by a clinical interview or a standardised psychometric assessment (Graham et al., 2007). These guidelines suggest that individual or group counselling, for coping with stress and illness, should be given to patients who experience stress or are at high risk and to those who have previously developed CVD.

Stress, as defined by Smith and Vale (2006), is a state in which there is a real or perceived threat to homeostasis. The physiological reaction to psychological stress in humans is primarily governed by a set of structures involving the hypothalamic-pituitary-adrenal (HPA) axis. Also known as the neuroendocrine response (Figure 1.2), this ultimately aims to mobilise energy stores by the synthesis and release of cortisol in order to initiate and regulate the 'fight or fight' response (Bear et al., 2007).

Although these physiological mechanisms are well perceived, their specific links to cardiovascular disease risks are not yet well understood (Steptoe and Kivimaki, 2012) because very few studies have explored this as a major focus (Chandola et al., 2008). However, epidemiological data does indicate that chronic stress predicts the occurrence of coronary heart disease (Steptoe and Kivimaki, 2012). In addition, employees who experience work-related stress, as outlined in theories by Siegrist (1996) (effort-reward) and Karasek (1979) (demand-control-support), have an increased risk of cardiovascular disease (Bosma et al., 1997, 1998, Backe et al., 2012, Djindjic et al., 2012). Therefore, as a common repercussion, employees at all levels may be subject to increased risk of developing a CVD.

Figure 1.2 The Hypothalamic-Pituitary-Adrenal Axis.

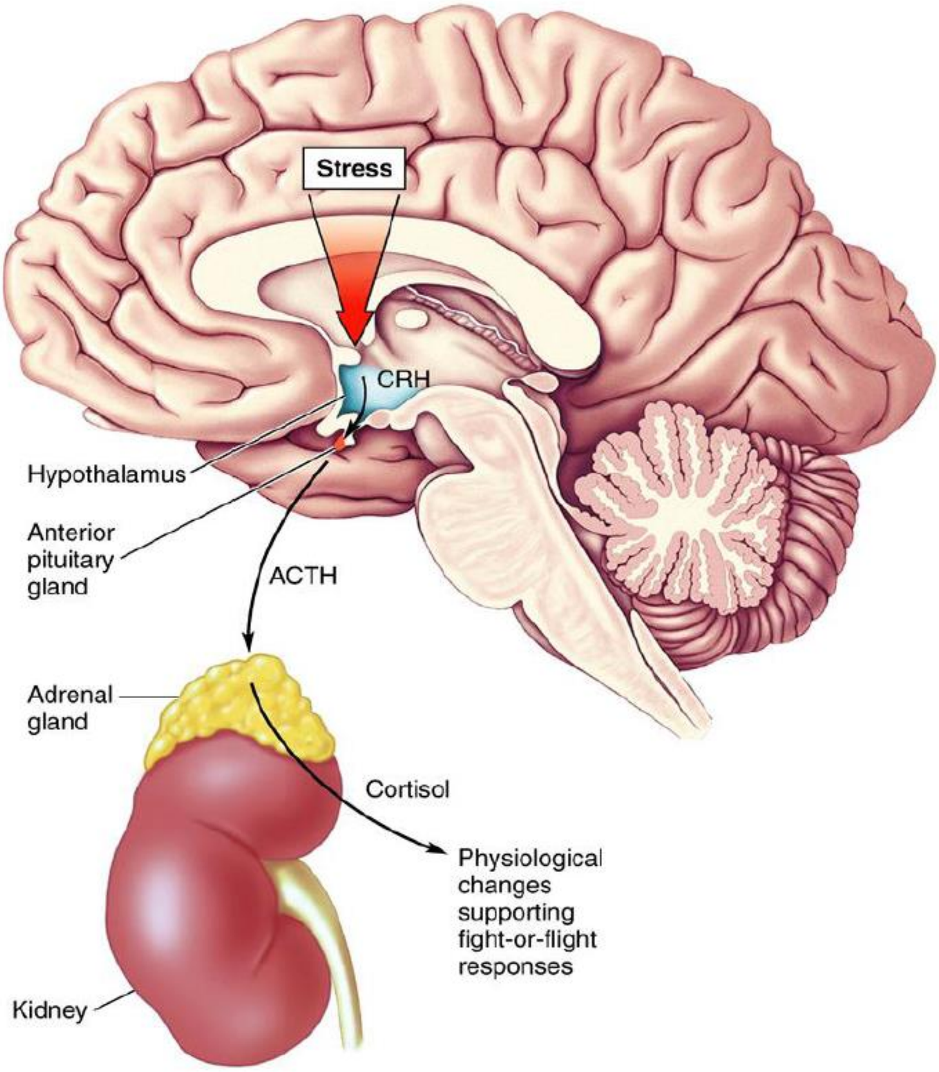


Figure 1.2 illustrates the role of the hypothalamic-pituitary-adrenal (HPA) axis in the physiological response to stress. In reaction to stressful stimuli, the hypothalamus releases corticotropin releasing hormone (CRH) to the anterior pituitary gland which in-turn releases adrenocorticotropic hormone (ACTH). The ACTH flows through the systemic circulation and initiates the synthesis and release of cortisol from the adrenal gland. This mobilises energy stores as well as other physiological changes which support the 'fight or flight' response. Image from Bear et al. (2007).

Key:
ACTH = Adrenocorticotropic hormone; CRH = Corticotropin releasing hormone

1.3 Executive Cognitive Function

Executive cognitive function refers to a family of mental processes which are recruited for concentration and attention (Chan et al., 2008, Diamond, 2013). The use of executive functions is demanding, (i.e., it is easier to continue a habit instead of changing it), and it is effortless to go on 'autopilot' rather than to consider what to do next (Diamond, 2013). Regarding executive function, the consensus amongst the literature is that there are three core branches. These branches are (i) inhibition and interference control, (ii) working memory (WM), and (iii) cognitive flexibility (Miyake et al., 2000, Lehto et al., 2003). Often these cognitive processes work simultaneously, and the focus of this study is directed specifically on WM and attention as key aspects of executive function (Section 1.3.2 and 1.3.3). These branches of cognitive function give rise to various derivations such as, problem solving, planning, reasoning, multi-tasking, sustaining attention, and decision making (Stuss et al., 1995, Burgess et al., 2000, Chan et al., 2008). In addition, these higher order cognitive abilities are essential for mental and physical health, and this has been extensively covered throughout the literature. For example, executive functioning has been shown to be impaired in various mental disorders including attention deficit hyperactivity disorder (ADHD) (Diamond, 2005), depression (Taylor Tavares et al., 2007), and obsessive compulsive disorder (Penades et al., 2007). These executive functions have also been implicated in various other aspects of health, such as obesity (Will Crescioni et al., 2011), occupational prosperity (Bailey, 2007), and public safety (Broidy et al., 2003). More importantly, executive functions have a relationship to CVD. Since CVD, globally, is the largest cause of morbidity and mortality, further investigation into these associations could prove paramount (Section 1.4)

Furthermore, different areas of executive function (e.g., planning, strategy, decision making, and intentionality) can be tested using various psychometric tools, for example, Dysexecutive Questionnaire (Wilson et al., 1996), Gambling Task (Damasio et al., 1994), and the Greenwich Test (Burgess et al., 2000).

1.3.1 Memory

One of the most fascinating and intricate functions of the brain is the ability to retain information gathered through experiences and to retrieve that information at will (Purves et al., 2004). This ability serves as a foundation for much of the other cognitive abilities that would otherwise not occur in the absence of this function. Common psychometric measures that indicate memory performance include the Weschler Memory Scale (WMS) (Wechsler, 1945) and the California Verbal Learning Test (Woods et al., 2006).

In addition, it is important to differentiate between learning and memory where the former is a process by which new information is gathered and the latter is the encoding, storage and retrieval of previously learned information (Purves et al., 2004). Qualitatively speaking, humans mainly have two different methods of information storage, declarative memory, and non-declarative memory (Figure 1.3). Declarative memory refers to the storage and retrieval of factual information accessible by the conscious mind, including mobile number, images, or songs (Squire, 1992, Squire and Zola, 1996). Non-declarative memory, also known as procedural memory, are a set of learning capacities, not available to consciousness, which involves skills, habits, and other abilities expressed through performance (Squire, 1992, Squire and Zola, 1996).

Figure 1.3 The Major Qualitative Classification of Human Memory

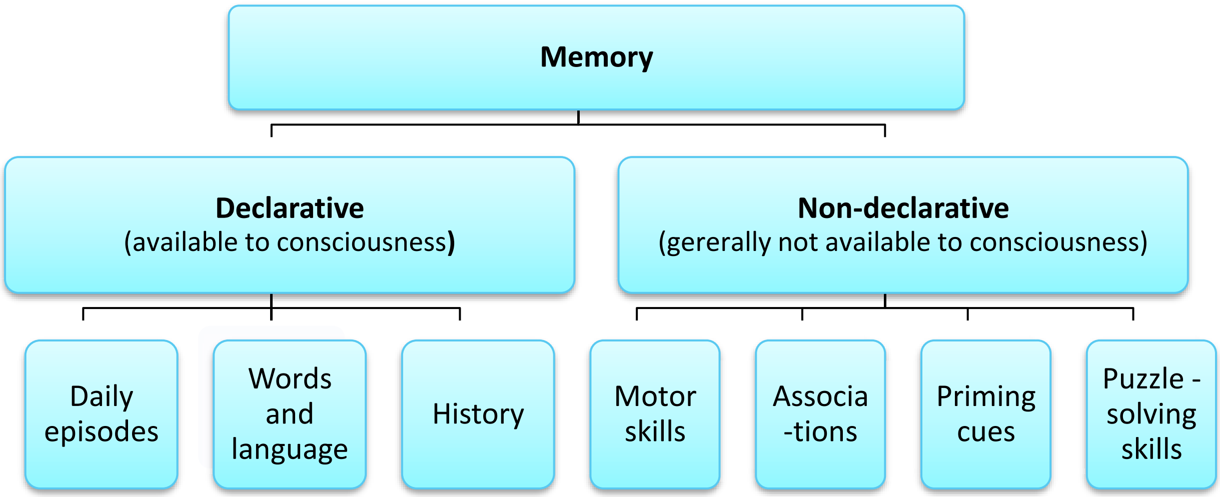


Figure 1.3 illustrates the qualitative categories of human memory. It differentiates between declarative and non-declarative (procedural) memory. The former refers to memories that are accessible to the consciousness, such as images, phone numbers, sounds etc., while the latter is generally not, for example motor skills, priming cues, habits, and other information that is accessed unconsciously. Image adapted from Purves et al. (2004), page 734.

Furthermore, instead of categorising memory by the nature of what is remembered, it can be differentiated according to the time period to which it is most relevant (Purves et al., 2004). The first is known as immediate memory, which refers to the ability to hold information for fractions of a second and involves sensory modes (e.g., visual, tactile) (Atkinson and Shiffrin, 1968, Purves et al., 2004). The second is short-term memory, which is the ability to hold information for periods of seconds to minutes (Cowan, 2008). Furthermore, short-term memory is said to be a subdivision of working memory, which is discussed in greater depth in Section 1.3.2 below. Lastly, the third temporal category of memory is long-term memory, which encompasses the retention of information in a more perpetual form (Purves et al., 2004). These can last from days and weeks to decades and even lifetimes. Moreover, the transfer from short-term storage to long-term memory storage requires a period of consolidation. This involves synaptic plasticity related to learning (Dudai, 2004) as well as a systems consolidation, whereby memories are reorganised from the hippocampus, where they are encoded, to the neo-cortex for a more lasting form of storage (Frankland and Bontempi, 2005, Roediger et al., 2007). It is also important to mention that forgetfulness plays an important role in memory. Common sense would imply that, forgetting useless information helps to reduce the burden of large and unorganised information that is briefly encoded by our immediate memory (Purves et al., 2004). Purves et al. (2004) further elaborates that "the ability to forget unimportant information may be as critical for normal life as retaining information that is significant". This time-dependant classification of memory is summarised in Figure 1.4.

Figure 1.4 Temporal Classification of Human Memory

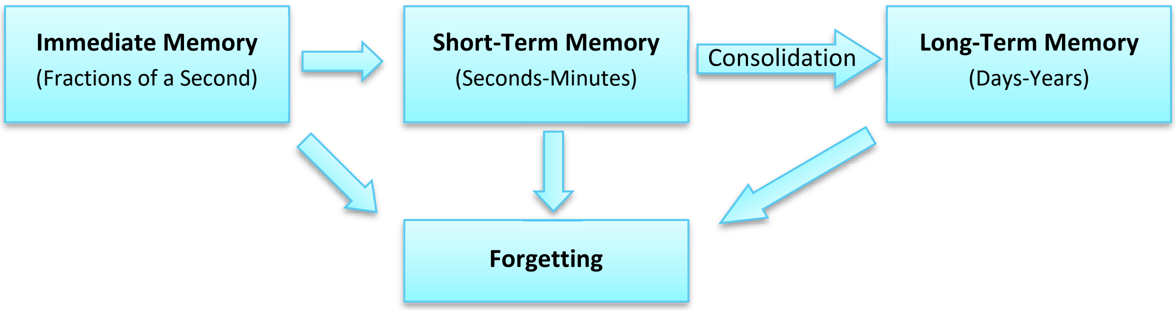


Figure 1.4 shows the major components of human memory, categorised by the time over which each is effective.

1.3.2 Working Memory

As previously highlighted, short-term memory and working memory (WM) coincide and their underlying concepts have proven to be problematic throughout the literature. This is significantly due to different authors using different definitions, as well as interchanging the terms synonymously due to their previously revised definition (Miller et al., 1960, Baddeley and Hitch, 1974). A review of current literature allows the utilisation of a more recent and well supported definition of short-term and WM, which are as follows. Short-term memory is simply the holding of information in mind (Cowan, 2008, Diamond, 2013). Working memory refers to an array of systems that are assumed to be necessary in the short-term storage as well as the manipulation of that information (Cowan, 2008, Baddeley, 2010, Diamond, 2013). Working memory is further differentiated into two types with respect to content; verbal and non-verbal (visual-spatial) (Diamond, 2013). Furthermore, it is a crucial component in making sense of things that may develop over time (i.e., it requires the holding of previous information and creating associations with what may come later) (Diamond, 2013). Therefore, WM is necessary in language, math, reorganising a to-do list, considering alternatives, reasoning, planning, decision making, creativity, and all other complex mental tasks (Smith and Jonides, 1999, Burgess et al., 2000, Miyake et al., 2000, Bailey, 2007, Hill et al., 2010).

The central executive, part of the prefrontal cortex (PFC), plays a crucial role in WM (Siddiqui et al., 2008). It serves as a temporary storage for short-term memory, where the information is held while it is needed for current reasoning processes, but also connects to other parts of the brain in order to make links with various pieces of information (Siddiqui et al., 2008). The central executive, an attentional control system, controls neural loops, which work in combination to temporarily hold and use current data until it is no longer needed (Baddeley, 2010). One is for visual material, the visuo-spatial sketchpad, one for verbal-acoustic material, the phonological loop, and one for combining different information, such as auditory and visual with possibly smell and taste, known as the episodic buffer (Park, 2007). This buffer provides temporary storage for information, that is coded separately, enabling their interaction through a multidimensional code and accessible through conscious awareness (Baddeley, 2010). A diagrammatic summary is shown below in Figure 1.5. Additionally, this conscious awareness, or focus of attention, is what allows the maintenance of various information in short-term storage (Awh et al., 2006, Fouginie, 2008) and, therefore allows its usage in working memory. This is further discussed in Section 1.3.3. Common testing procedures of working memory include the Digit Span (Weschler, 2009) and the n-back, which was originally developed by Kirchner (1958).

Figure 1.5 The Multi-Component Model of Working Memory

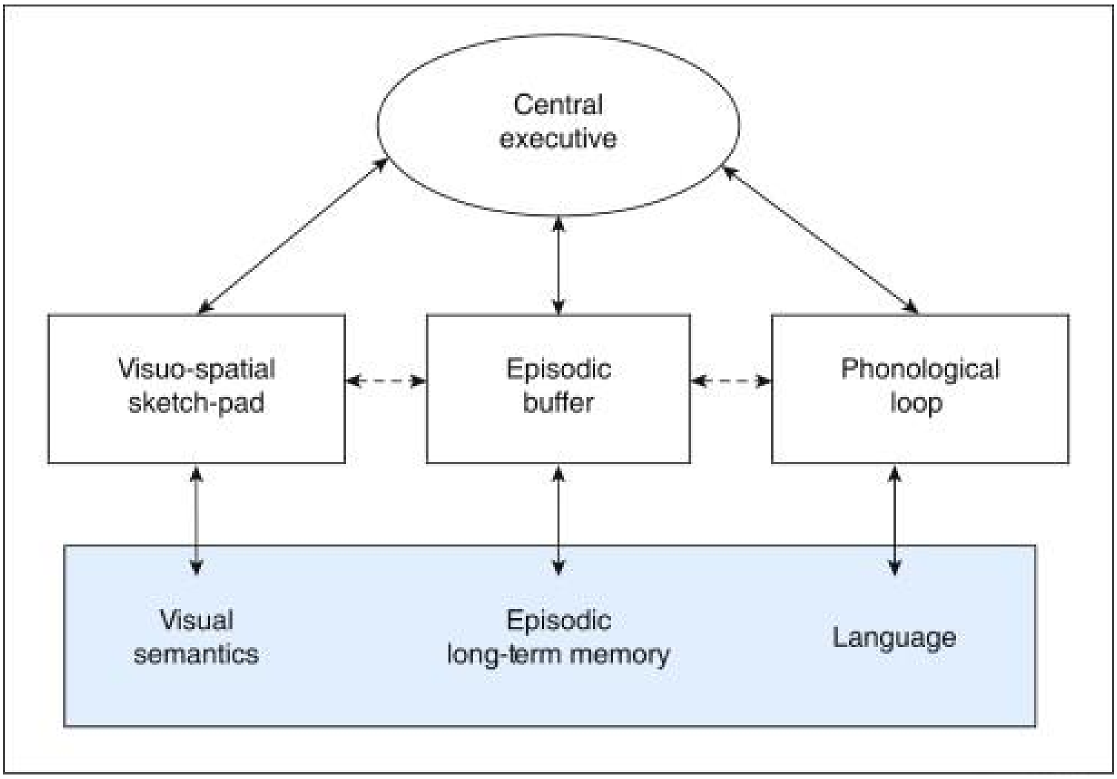


Figure 1.5 shows a later development of the multi-component model of working memory. It shows the links with long-term memory as well as the introduction of a fourth component, the episodic buffer. This buffer allows for different information to interact and be temporarily stored. Image sourced from Baddeley (2010).

1.3.3 Attention

As previously mentioned, the literature consistently cites inhibition, or inhibitory control, as one of the core executive functions (Diamond, 2013). The other two being working memory and interference control. Inhibitory control involves the ability to control attention, behaviour, and emotions to overrule an internal predisposition and do what is appropriate (Diamond, 2013). Otherwise, we would be at the mercy of old habits and impulses, disallowing change and adaption. The inhibitory control of attention (which is the aforementioned interference control, only at the perceptive level) allows us to attend and focus selectively, whilst suppressing attention to other stimuli (Diamond, 2013). In addition, selective attention and WM are similar in various ways, including at the neural level. The prefrontal cortex and posterior parietal cortex are crucial neural substrates for WM and attention (Ikkai and Curtis, 2011). Several studies have confirmed that the prefrontal parietal system that supports WM, allows the selective focus on information in the mind whilst discarding irrelevant thoughts and substantially overlaps with the prefrontal parietal system which helps the selective attention to stimuli in the environment whilst discarding irrelevant stimuli (LaBar et al., 1999, Awh and Jonides, 2001, Ikkai and Curtis, 2011, Gazzaley and Nobre, 2012, Diamond, 2013). Contrary to previous assumptions, Fouginie (2008) draws more distinctions between attention and WM suggesting that attention only plays a minor role in the maintenance of WM. The author further refers to its significance for the encoding and manipulation of information in WM. This implies the need for theories to consider the multifaceted nature of these complex systems. Moreover, the literature still lacks the fundamental understanding of the relationship that exists between WM and attention, of which there is no clear consensus and these rudimentary questions remain unanswered (Fouginie, 2008).

A continuous performance task (CPT), first reported by Beck et al. (1956) is used to assess attention. However a more recent and common measure of attention is the Integrated Visual and Auditory CPT (Tinius, 2003). These tasks are usually part of a large battery of tasks, used, to better understand the executive function of a person or patient.

1.4 Executive Function and Cardiovascular Disease

There is a growing body of evidence to suggest that associations exist between cognitive and executive performance and various cardiovascular diseases (Hofman et al., 1997, Prins et al., 2005, Muller et al., 2007, Dardiotis et al., 2012). The exact mechanisms of the aforementioned connection remains unclear, however, it seems that micro-embolism, cerebral hypoperfusion and cerebral vessel reactivity, which lead to cerebral hypoxia and ischemic brain damage, underlie cognitive impairment in heart failure (Dardiotis et al., 2012). Notably, the Rotterdam study indicated associations between Alzheimer's disease and indices of atherosclerosis and further demonstrated the prevalence of dementia increased with severity of atherosclerosis (Hofman et al., 1997). In addition, several studies suggest that not only has cognitive function been associated to CVD and atherosclerotic indices (Breteler et al., 1994) but also to peripheral vascular disease (Phillips and Mate-Kole, 1997), and to CVD risk factors (Kalmijn et al., 2002, Piguet et al., 2003, Gunstad et al., 2007).

Interestingly, Rostamian et al. (2015) investigated the relationship between executive function, memory, and incidence of coronary heart disease in a longitudinal study. The study included 3900 elderly participants (mean age 75 years, 44% male) at risk of CVD from the Prospective Study of Pravastatin in the Elderly at Risk (PROSPER) (Ford et al., 2002). The Stroop Colour-Word Test (Stroop, 1935b) for selective attention, and the Letter Digit Substitution Test (van der Elst et al., 2006) for processing speed were performed. Both tests combine to represent executive function, and the Picture Learning Test (Houx et al., 2002) is used to decipher memory function. During a 3.2 year follow up, participants in the lowest third of executive function had a 1.85-fold (95% confidence interval) greater risk of coronary heart disease (CHD) as compared to those in the top third. Intriguingly, the study did not find significance in the increased risk of CHD or stroke with respect to low memory capabilities (Rostamian et al., 2015). In accordance, Hogue et al. (2006) discovered that of the 108 female patients (age >55 years), prior to cardiac surgery, 35% (49) were categorized as having pre-existing impairments in cognition. As such, increasingly severe manifestations of CV risk and disease may, therefore, be correlated with a progression of neurocognitive deterioration. In further support of this, associations have been made between clinical and subclinical CVD, and diminished cognitive function (Waldstein and Wendell, 2010). Despite the compelling evidence relating CVD to cognitive dysfunction, investigations into the underlying mechanisms that connect working memory and cardiovascular health remain quite scarce.

1.4.1 Working Memory, Attention and Cardiovascular Disease

Increasing evidence suggests an association between CVD and cognitive decline, however, only a small number of studies have delved into the inner workings which relate working memory (WM) to CVD. To elucidate this relationship, Haley et al. (2007) utilised a verbal working memory (VWM) task, functional magnetic resonance imaging (fMRI), as well as B-mode ultrasound to detect the thickness of the two innermost layers of the artery wall, known as intima-media thickness (IMT). Studying thirteen participants (4 females and 9 males, mean age 69 ± 6.9 years), Haley et al. (2007) discovered that higher intima-media thickness correlated with decreased brain activity in the right posterior middle frontal gyrus regardless of patient age or degree of small vessel disease. According to Smith and Jonides (1997), this region of the brain is involved in subvocal rehearsal in VWM. In accordance, Haley et al. (2007) stipulated the association between atherosclerosis and brain dysfunction in specific areas of the brain crucial for VWM function. In contrast to the findings of Haley et al. (2007), Grubb et al. (2000) investigated the memory function of patients with stable, and moderate to severe cardiac failure and found no significant impairment in working memory. The heart failure group in this study however exhibited a higher prevalence of anxiety and depression. Although there are some contradictions in the scientific literature, previous studies indicate that anxiety and depression may have interfered with the results (Burt et al., 1995, Ilsley et al., 1995, Kizilbash et al., 2002). Additionally, many previous studies linking memory and working memory deficits to cardiac failures have mostly focused on patients with severe CVD (Bornstein et al., 1995, Roman et al., 1997). What is lacking throughout the literature is a comparison between different stages of heart disease and working memory function.

The direct relationship between attentional control and cardiovascular disease remains largely unexplored. However, few studies have discussed heart rate variability with respect to attention (Section 1.5.4 below). Further, some researchers have demonstrated connections between attention and affective disorders, where chronic worrying may be related to an increased risk of CHD (Kubzansky et al., 1997), and affective disorders such as anxiety and depression, may be linked to an increased risk of CVD (Aromaa et al., 1994, Hayward, 1995, Rugulies, 2002). This suggests an indirect association between cognitive processes and changes in heart rate variability (HRV) parameters (Section 1.5, 1.5.3, and 1.5.4 for relevant literature).

1.5 Heart Rate Variability

Heart rate variability (HRV) is the physiological phenomenon of the variation in time between successive heart beats (Heathers, 2014). Analysis of HRV allows for a non-invasive measure to be taken of the autonomic input into the heart (Pumprla et al., 2002). Higher measures of HRV indicate healthy autonomic nervous system control and also signify an individual’s ability to adapt and react to their given surroundings (Pumprla et al., 2002), whilst reduced measures of HRV signify poor autonomic regulation of the heart (Colhoun et al., 2001).

The sinus node, the pacemaker of the heart, regulates contractions to accommodate metabolic demand. It has innervation from both the sympathetic and parasympathetic divisions of the ANS (Pumprla et al., 2002). Parasympathetic modulation occurs via the vagus nerve through acetylcholine release, which is metabolised relatively quickly, as opposed to sympathetic modulation from the stellate ganglia through noradrenaline release at the sinus node, which is metabolised slowly (Pumprla et al., 2002). The turnover rates of these chemical transmitters produce variations and fluctuations in frequencies and HR, producing a complex variability identified by HRV analysis (Thayer et al., 2009). These variations have been established and quantified to indicate different bandwidth frequencies at which the two branches of the ANS function (Thayer et al., 2009). Baseline HR is controlled by tonic inhibition, which is driven by parasympathetic activity. This concept was demonstrated by Jose and Collison (1970) through the use of propranolol and atropine to block parasympathetic and sympathetic activity, respectively, which lead to an increased intrinsic HR compared to baseline. Vagal modulation has since been hypothesised to favour energy conservation (Thayer and Brosschot, 2005).

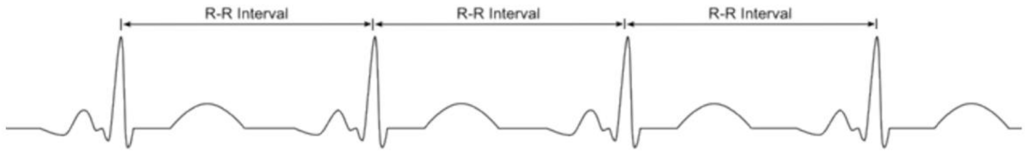
1.5.1 Frequency Domain HRV

Power spectral analysis separates HRV into its frequency components. In order to derive, process, and analyse HRV, certain steps must be followed, as illustrated below in Figure 1.6. First, an electrocardiogram (ECG) recording is taken (Figure 1.6i). Secondly, the time intervals between successive beats of the heart are measured (Figure 1.6ii). And finally, the fast Fourier transform (FFT) is applied which results in an end display of the power spectrum (Figure 1.6iii). The power spectrum illustrates the various autonomic influences on the heart (Pichon et al., 2006), which is depicted below.

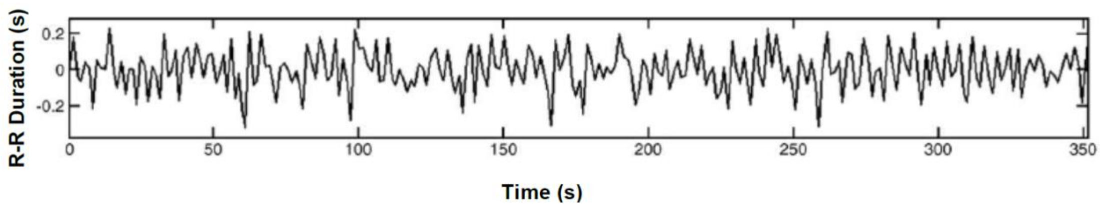
The high frequency (HF) power band of HRV primarily reflects parasympathetic activity (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The low frequency (LF) power band represents the activity of both the sympathetic and parasympathetic nervous system (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The interaction between the two branches, the sympathovagal balance, can be indicated by the LF/HF ratio (Prakash, 2012).

Figure 1.6 Derivation of Heart Rate Variability

i) Electrocardiogram Recording



ii) Time Series Graph



iii) Power Frequency Spectrogram

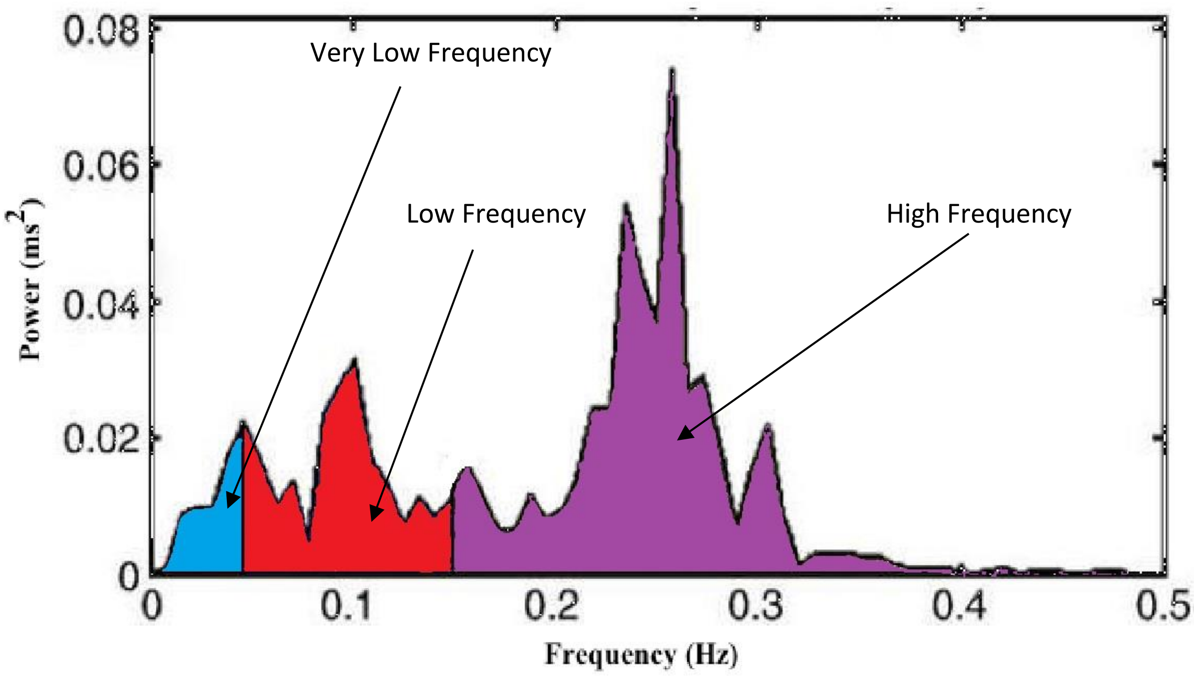


Figure 1.6 illustrates the steps required to derive autonomic influences responsible for heart rate variation. i) Shows the R-R intervals on an electrocardiogram recording. ii) Represents the plot of R-R intervals on a time series graph. iii) Illustrates the power frequency spectrogram obtained after the application of the fast Fourier transform to the time series graph. Image adapted from Pichon et al. (2006).

Key:

- = Very Low Frequency (0.00 to 0.04Hz)
- = Low Frequency (0.04 to 0.15Hz)
- = High Frequency (0.15 to 0.40Hz)

Hz = Hertz; ms^2 = Milliseconds squared; R = Peak of the wave; R-R-interval = Time between successive heart beats; s = Seconds

1.5.2 Time Domain HRV

Heart rate variability can further be examined as a function of time. The time domains presently used include HR, mean R-R interval, standard deviation of NN intervals (SDNN), root mean square of successive differences (RMSSD), and the percentage of NN intervals greater than 50 milliseconds (pNN50) (Table 1.1). The other geometric and non-linear measures of time domain HRV require recordings longer than 10 minutes and therefore were not applicable to this study (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Additionally, as the length of the recordings increase the amount of time variance also increases and therefore, it is recommended to compare recordings of similar length (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

The RMSSD and pNN50 indicate vagal input to the heart and are correlated with HF activity (Achten and Jeukendrup, 2003). The SDNN has more mixed autonomic input from both branches as well as respiratory and circadian influences which can be comparable to total power (TP) (Billman, 2011).

The literature has stipulated that decreases in time domain HRV, particularly RMSSD, measures are linked to decreases in parasympathetic input (Billman, 2009, Li et al., 2009). This reduction in parasympathetic activity has been linked to CVD, as discussed in Section 1.5.3 (Counihan et al., 1993, Thayer et al., 2010).

Table 1.1 Time Domain Heart Rate Variability Parameters

HRV Measure	Description
SDNN (ms)	**Standard deviation of all NN intervals (Square root of the variance)**
SDANN (ms)	Standard deviation of averaged NN intervals calculated from a series of epochs of identical durations (5-minute segments) for the entire recording
RMSSD (ms)	**Square root of the mean squared differences of successive NN intervals**
SDNN index (ms)	Mean of the standard deviations of all NN intervals for all 5-minute segments of the entire recording
SDSD (ms)	Standard deviation of differences between adjacent NN intervals
NN50 count	Total number of interval differences (>50ms) of consecutive NN intervals
pNN50 (%)	**NN50 count divided by the total number of NN intervals**

Table 1.1 describes the range of time domain measures of HRV. The parameters in bold were used in the present study. Adapted and modified from Tarvainen et al. (2009) and Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996).

Key: HRV = Heart rate variability; Hz = Hertz; ms = Milliseconds; ms^2 = Milliseconds squared; NN = Consistent point on the electrocardiogram trace between two cardiac cycles; > = Greater than; % = Percentage

1.5.3 Heart Rate Variability, the Autonomic Nervous System, and Cardiovascular Risk

The autonomic nervous system (ANS) plays a major role in many diseases as it controls all the bodily functions and processes that do not require our conscious attention. In conjunction with the somatic nervous system, it makes up the peripheral nervous system (PNS), the main function of which is to connect the central nervous system to the limbs and organs. The ANS itself consists of the sympathetic and parasympathetic division. The former is responsible for the mobilisation of energy stores and the "fight or flight" response, and the latter is associated with the vegetative and restorative functions of the body (Bear et al., 2007). Evaluation of various autonomic influences on the heart may be an indication of cardiovascular risk (Goldberger, 1999). Autonomic cardiac activity is intrinsic to the pacemaker tissue of the myocardium (Hamaad et al., 2004), as such, despite substantial ANS control, the cardiac risk does not necessarily reflect reduced nervous system activation (Colhoun et al., 2001).

Moreover, it is the imbalances between the ANS branches that lead to a myriad of health complications. This is where HRV can be used to assess certain health complications where previous research indicates that, generally, parasympathetic drive is underactive and sympathetic drive is overactive (Thayer et al., 2010). In addition, time and frequency domain parameters (Table 1.1 and Table 1.2) have successfully indicated vagus nerve activity (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Throughout literature there is a strong consensus that the high frequency (HF) power band of HRV primarily reflects parasympathetic influence (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). However, despite the indication of vagus nerve activity, contention exists in the literature regarding the low frequency (LF) power band where LF has been associated not only with the sympathetic nervous system but also to the parasympathetic division, as well as baroreceptor input (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). In addition, the interaction that occurs between both branches of the ANS can be measured via the LF/HF ratio (Prakash, 2012). This is an indication of the sympathovagal balance (Prakash, 2012). This originates from autonomic influences on the sinoatrial node of the heart. Despite the inconclusive definition surrounding sympathovagal balance, it is recognised to provide a holistic insight into the interactions of the ANS branches at the pacemaker cells of the heart (Eckberg, 1997).

Table 1.2 Frequency Domains of Heart Rate Variability

HRV Measure	Frequency	Autonomic Branch
High Frequency (HF)	0.15 – 0.40 Hz	Parasympathetic
Low Frequency (LF)	0.04 – 0.15 Hz	Sympathetic
LF/HF Ratio	(0.04-0.15) / (0.15-0.50) Hz	Sympathovagal Balance

Table 1.2 shows the distinctions between heart rate variability bands via frequency. Table sourced from Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996).

Key: HF = High frequency; HRV = Heart rate variability; Hz = Hertz; LF = Low frequency; LF/HF Ratio = Sympathovagal balance

There is mounting evidence throughout the literature to support strong associations between decreased HRV and mortality (Tsuji et al., 1996, Colhoun et al., 2001, Thayer et al., 2010). Furthermore, HRV is known to be reduced by various cardiovascular health complications. Kleiger et al. (1987) indicated a significant decrease in the HRV of patients that survived a myocardial infarction (MI). The investigators further highlighted a fivefold increase in the probability of death via coronary artery disease and ageing as compared to those displaying higher levels of HRV. Kleiger et al. (1987) further established a connection where decreased HRV may be associated with specific decreases in parasympathetic drive or increases in sympathetic drive to the cardiac muscle, which provided the basis for many later studies assessing HRV and cardiac health (Watson et al., 2007, Olshansky et al., 2008, Triposkiadis et al., 2009). A summary of clinically significant research is presented in Table 1.3, which highlights the relevance of autonomic modulation as a crucial element in CVD.

As previously mentioned, contrasting findings exist regarding HRV frequency, however, the prevailing consensus remains that HRV reductions are strongly associated with increases in the risk of developing CVD (Vrijkotte et al., 2000, Lombardi et al., 2001, Thayer et al., 2010). In addition, for all risk factors of cardiovascular disease (Section 1.2), empirical evidence exists to suggest associations with reduced HRV (Liao et al., 2002). Therefore, HRV can be a significant predictor of cardiovascular disease.

Table 1.3 Summary of Research Investigating HRV in Cardiovascular Health

Authors	Disease	Sample Size	Clinical Finding
Lombardie et al. 1987	Acute Myocardial Infarction	70 Acute MI 26 Normal	↑ LF, ↓ HF
Saul et al. 1988	Congestive Heart Failure	25 Chronic CHF 21 Normal	↓ All frequencies. Especially >0.04Hz
Casolo et al. 1989	Congestive Heart Failure	20 CHF 20 Normal	↓ HRV
Guzzetti et al. 1991	Hypertension	49 Hypertensive 30 Normal	↑ LF
Counihan et al. 1993	Hypertrophic Cardiomyopathy	104 Hypertrophic	↓ Measurements of vagal tone HRV
Colhoun et al. 2001	Coronary Artery Calcification	160 Diabetic 163 Non-Diabetic	↓HRV

Table 1.3 summarises the findings of various investigations of heart rate variability in different cardiovascular diseases.

Key: CHF = Congestive heart failure; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; MI = Myocardial infarction; ↑ = Increase; ↓ = Decrease; > = Greater than

1.5.4 Heart Rate Variability, Working Memory, and Attention

One underlying process that has been shown to have a relationship with the understanding of memory and attentional systems is the activity of the cardiovascular system (Hansen et al., 2003, Duschek et al., 2009, Luft et al., 2009). Evidence for this notion is outlined in Table 1.4. From the first suggestion of using HRV to provide insight into autonomic abnormalities in disease (Eppinger et al., 1917), Porges and Raskin (1969) were one of the first to demonstrate a significant reduction in HRV during sustained attention. Moreover, Backs and Seljos (1994) utilised a continuous memory task to assess the relationship between memory load and HRV. It was discovered that as memory load increased, good performers had a small HRV decrease, whilst poor performers indicated a large HRV decrease. In addition, it was also noted that blood pressure (BP) variability and HRV were impacted by executive memory and attentional tasks (Middleton et al., 1999). Middleton et al. (1999) found both attentional and planning tasks raised blood pressure, however, changes in blood pressure variability and HRV were confined to attentional tasks. Nevertheless, executive functions require higher mental load capacities, therefore, a suppression of HRV during both attentional and working memory tasks can be expected. Interestingly, Backs et al. (1994) used a range of physiological measures to determine autonomic vagal influence on workload and manual performance to elucidate further relationships between HRV and memory and attention systems. This study indicated that central processing demands had specifically affected sympathetic cardiovascular control, whilst the physical demands were reflected in parasympathetic cardiovascular control. This suggests that cardiovascular measures are a result of differential activation in the ANS. In contrast, Richards (1987) and Suess et al. (1994) both substantiate vagal tone as an index of mental effort, since higher resting cardiac vagal influence was associated with better attention.

Table 1.4 Supporting Evidence Linking HRV and Executive Function

Authors	Sample	Executive Function	Finding
Porges and Raskin (1969)	48 Males	Attention	Reduced HRV
Redondo and Del Valle-Inclan (1992)	24 (Gender Unspecified)	Memory-search	Reduced HRV
Backes and Seljos (1994)	12 Males 12 Females	Working Memory	GP = High HRV PP = Low HRV
Vincent et al. (1996)	31 Males	Memory Encoding	Suppressed HRV
Hansen et al. (2003)	53 Males	Working Memory	Higher HRV = Better Accuracy
Duschek et al. (2009)	28 Males 32 Females	Mental Task	Reduced HRV Increased Sympathetic Decreased Parasympathetic
Luft et al. (2009)	23 Males 7 Females	Working Memory	Reduced LF/HF Ratio
Muthukrishnan et al. (2015)	24 Males	Visuo-Spatial Working Memory	Reduced HRV Higher HRV = Better Performance

Table 1.4 shows various studies contributing to the understanding of the link between cognitive executive function and autonomic cardiac modulation. The prevailing consensus indicates that mental load is associated to a reduction of autonomic vagal control. Furthermore, it is also well known that individuals that have superior executive functioning show less reduction in overall HRV, whilst the inverse applies to those with inferior capabilities.

Key: GP = Good performance; HRV = Heart rate variability; PP = Poor performance

A more equivocal question would be if HRV can be used as an independent factor in the prediction of cognitive performance (Hansen et al., 2003), however, such studies are scarce. Hansen et al. (2003), for the first time, established a relationship between HRV and performance tasks that taxed executive function in normal subjects (n = 53 male, average age = 23 years). This study found that the qualitative differences between task demands could be predicted by the subject's cardiac vagal tone. Other researchers have investigated this connection, however, vagal tone relationships remain largely undiscovered (Gianaros et al., 2004). Furthermore, in order to predict cognitive performance, by utilising cardiac vagal tone as an independent variable, Johnsen et al. (2003) investigated attentional bias in 20 patients with anxiety in a dental setting using a modified Stroop-test (Stroop, 1935b) (n = 14 male and n = 6 female, mean age = 36 years). Results showed that poor attentional performance was characterised by reduced HRV as compared to patients with higher HRV (Johnsen et al., 2003). Due to subjects having to keep in mind the instructions, to be able to select the correct response, the Stroop-task can be regarded as a task that recruits the use of executive functions (Stroop, 1935b). As such, the low HRV group were regarded as representing a low degree of neurovisceral integration and a reduced ability to assemble resources to meet the demands that are required in an attentional task (Johnsen et al., 2003). These results further highlighted the importance of vagal-mediated cardiac control with respect to attention, emotion, and other physiological processes (Johnsen et al., 2003). Despite the findings, the study had been performed in a clinical population with pre-existing conditions such as anxiety. Therefore, the predictive relationship between HRV, WM and attention remains to be established in a healthy population.

In addition, Hansen et al. (2003) noted differences between high and low HRV groups in tasks involving executive functions. These findings were strengthened by results found on a working memory task (WMT) that only taxed central executive functions. This determined that superior performance on the WMT was characterised by increased vagal modulation in cardiac control. In contrast, the authors found that participants with low vagal tone indicated a lesser ability to match cognitive abilities to the environmental demands. It was further reported that two out of three tests showed better executive performance for subjects with higher HRV as opposed to lower HRV (Hansen et al., 2003). This reinforces the argument that HRV measures may be able to differentiate between good and poor performance in executive function and thus, serve as a predictive measure in determining any impairments in cognition.

In a more recent study, Muthukrishnan et al. (2015) investigated the relationship between HRV and visuo-spatial working memory. Participants, (n = 24, males, average

age = 28 years), were subject to a working memory paradigm which involved simultaneous encoding, maintenance, active manipulation, and retrieval. This study further segregated subjects into two groups of good performers and bad performers, which then revealed a concurring finding with that of previous literature (Backs and Seljos, 1994, Hansen et al., 2003). This indication, of decreased HRV with increased working memory load and higher HRV in better performers, supports the notion that, during working memory function, HRV may qualitatively predict cognitive differences among individuals (Muthukrishnan et al., 2015). This also implies that executive performance and autonomic functions, such as that of HRV, may be adaptively regulated by an interrelated neural network. Therefore, HRV may provide an index of an individual's ability to function effectively in a dynamic environment (Muthukrishnan et al., 2015).

1.6 Basis of Research

In the 21st century, there has been, and is, a significant and ever-growing focus on corporate performance and workforce productivity. These professions require the collective utilisation of various cognitive and executive functions simultaneously. It has been shown throughout the literature that decrements in cognitive ability are associated with reductions in performance. In addition, there is an ever-increasing accumulation of unequivocal evidence to suggest an increased risk of cardiovascular disease is related to declines in cognitive function (Muller et al., 2007, Angermann et al., 2012).

The notion that a relationship exists between higher cognitive systems, executive functions, and changes in various physiological systems, has been around for a long time (Porges and Raskin, 1969). Investigations throughout the literature have used both psychometric and physiological assessments to better understand these relationships. Furthermore, the literature stipulates certain correlations between autonomic cardiac modulation and executive functioning (Table 1.4). These studies suggest that there is an overall reduction in cardiac autonomic control during executive functions, such as working memory and attention. Moreover, increased vagal stimulation of autonomic cardiac activity during executive functions seems to allow for better performance.

Limited research has linked working memory and attentional deficits to cardiac deficits (Haley et al., 2007) and these studies focused on end stage patients (Rostamian et al., 2015). More research needs to be performed in healthy subjects including corporate workers. This will allow for the present study to add to contemporary literature where HRV may present as a pre-emptive biomarker for working memory and attentional performance. Furthermore, the literature surrounding executive function has been performed in small sample numbers, which, may not accurately portray the correlations present among these variables. Despite several studies assessing the relationships between executive function, cardiovascular disease and autonomic regulation of the heart, the direct association between working memory, attention and HRV remains largely unexplored. In addition, the underlying and fundamental examinations of these relationships are currently inadequate.

Thus, the present study aims to address the void in the literature by investigating executive function, particularly working memory and attention, in two major working populations (n = 48 white-collar workers, and n = 53 blue-collar workers). The use of validated, accurate and reliable measures, such as heart rate variability, and executive function assessments taken from the Cambridge Neuropsychological Test Automated Battery (CANTAB) (Cambridge Cognition, 2021) will allow for comparative analysis to be subsequently performed. This will further identify the fundamental associations between working memory, attention and, heart rate variability in a healthy working population.

1.7 Aims

The overall aim of this research was to investigate the links between cardiovascular autonomic activity (assessed using HRV) and neurocognitive performance in blue- and white-collar workers.

More specifically, the aims of the present research were to examine the:

1) Differences in heart rate variability parameters between baseline and active phase (neurocognitive performance tasks) within the blue- and white-collar workers.
2) Associations between heart rate variability parameters and neurocognitive performance measures in the blue- and white-collar workers.
3) Differences in heart rate variability parameters between the blue- and white-collar workers.
4) Differences in neurocognitive performance between the blue- and white-collar workers.
5) Differences in neurocognitive performance measures between data categorised into high HRV groups and low HRV groups in both blue- and white-collar workers.

1.8 Hypotheses

The hypotheses for the present research were as follows:

1) Differences will be observed in heart rate variability between baseline and active phases (neurocognitive performance tasks) for blue- and white-collar workers.
2) The blue- and white-collar groups will show associations between HRV and neurocognitive performance measures.
3) There will be differences in heart rate variability parameters between the blue- and white-collar workers.
4) There will be differences in neurocognitive performance between blue- and white-collar workers.
5) High HRV groups and low HRV groups will exhibit differences in neurocognitive performance measures in both the blue- and white-collar workers.

Chapter 2 Materials and Methods

The following research procedure was developed to address the aims and hypotheses outlined in Chapter 1. This cross-sectional study was designed to assess a sample of healthy participants. The ethics for the experimental protocol outlined below was approved through the University of Technology Sydney Human Research Ethics Committee (HREC: 2014000110) and was conducted in the Neuroscience Research Unit (NRU) at the University of Technology Sydney.

2.1 Participant Recruitment

Participants between the ages of 18-68 years (n = 101) were recruited from the community. Participants were required to abstain from caffeine and nicotine for 4 hours, and alcohol for 12 hours, prior to the commencement of testing. These factors are known to influence physiological measures and their restrictions enhance the reliability of the data (Hayano et al., 1990, Murata et al., 1992, Elghozi et al., 2001).

Testing was conducted between 8:30 am and 12:00 pm to minimise the effect of circadian rhythm fluctuation (Roeser et al., 2012) on the data obtained.

2.2 Consent

Potential candidates were supplied with a detailed information sheet as well as a verbal explanation of the procedure and given the opportunity to ask any questions. The consent form was then read and signed by both participant and researcher, and each party retained a copy. Participants were further informed of their ability to withdraw from the study, at their discretion, without having to provide a reason.

2.3 Volunteer Eligibility

This study had several inclusion criteria which had to be met for the eligibility of participants to undertake this study, as per HREC requirements. Furthermore, participants were screened for any ongoing health issues or diseases that have a known effect on the cardiovascular system, autonomic nervous system, and executive cognitive function. This screening was performed by a modified and adapted version of the Lifestyle Appraisal Questionnaire (LAQ) (Craig et al., 1996).

Furthermore, the participant's blood pressure (BP) measurements were also taken which determined eligibility according to UTS HREC requirements. The volunteer was seated, and three brachial BP readings were recorded and then averaged. Average of the three readings provided greater accuracy and reduced the effects of white coat hypertension (Le Pailleur et al., 1998). If the systolic BP measures were greater than or equal to 160 mmHg and/or diastolic BP measures were greater than or equal to 100 mmHg, the participant was excluded and offered to be escorted to the nearest medical centre. This is also in accordance with the guidelines of the National Heart Foundation of Australia (2010) where moderate hypertension is reflected by BP values greater than 160/100 mmHg (Table 2.1). Moreover, volunteers with recorded BP greater than 140/90 mmHg but less than 160/100 mmHg were included, however, were advised to consult their GP for the elevated level (ethics protocol requirement).

Table 2.1 Blood Pressure Classification in Adults

Diagnostic Category	Systolic (mmHg)	Diastolic (mmHg)
Normal	<120	<80
High-normal	120-139	80-89
Grade 1 (mild) hypertension	140-159	90-99
Grade 2 (moderate) hypertension	160-179	100-109
Grade 3 (severe) hypertension	≥180	≥110

Table 2.1 stipulates the different categories of BP. Normal BP (<120/80 mmHg), high-normal BP (120-139/80-89 mmHg), grade 1 or mild hypertension (140-159/90-99 mmHg), grade 2 or moderate hypertension (160-179/100-109 mmHg), grade 3 or severe hypertension (≥180/≥110 mmHg). Adapted from the National Heart Foundation Australia (2010).

Key: BP = Blood pressure; ≥ = Greater than or equal to; < = Less than; mmHg = Millimetres of mercury

2.4 Research Protocol

Participants were required to abstain from alcoholic beverages for 12 hours and caffeine and smoking for 4 hours prior to study participation. These substances have known effects on the central and peripheral nervous systems which may influence the results obtained in this study (Hayano et al., 1990, Reed et al., 1999, Elghozi et al., 2001).

This experiment was conducted in a controlled setting, which minimised the influence of external visual, auditory, and thermal stimuli. Following an explanation of the experimental protocol to the participant, as well as obtaining signed consent, the study commenced as follows.

2.4.1 Blood Pressure Measurement

The subject remained seated for 5 minutes prior to three BP recordings using an automated monitor (OMRON IA1B, Japan) (Figure 2.1). The BP cuff was placed two centimetres above the elbow of the left arm where it aligns at the same level as the heart (Figure 2.2). Three blood pressure readings were obtained both before and after the study protocol, with 2-minute intervals between each measurement (Pickering et al., 2005).

Figure 2.1 The OMRON IA2 Automatic Blood Pressure Monitor

Figure 2.1 depicts the automated BP monitor used in this study. The standardised instructions are shown for correct placement, i.e., 1-2 centimetres above the elbow pit, to occlude the brachial artery.

Key: cm = Centimetres, DIA = Diastolic, min = Minutes, mmHg = Millimetres of mercury

Figure 2.2 Instructions for the Use of the Automated Blood Pressure Monitor

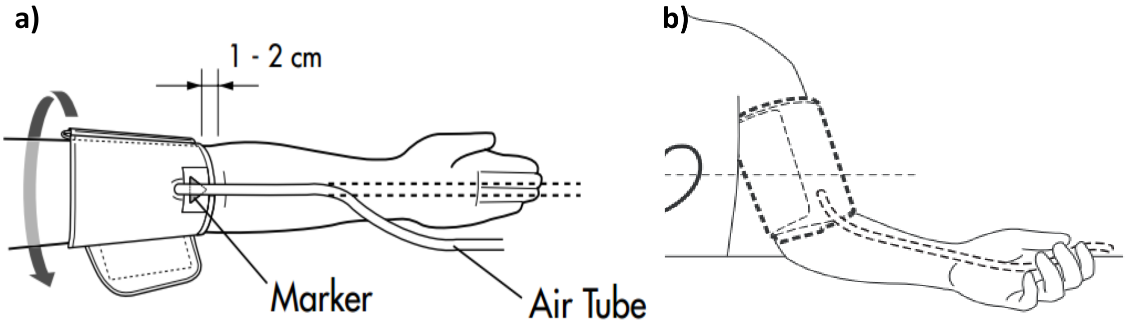


Figure 2.2 shows a pictographic representation of correct cuff placement of the BP monitor. The cuff must be placed 1-2cm above the elbow with the air tube flowing in the direction of the forearm and in line with the two middle fingers. b) Illustrates the placement at the same level as the heart with the arm fully supported by a bench or table. Image adapted from OMRON Australia (2015).

Key: BP = Blood pressure; cm = Centimetre; --> = Direction

2.4.2 Electrocardiogram

The participant underwent a baseline electrocardiogram (ECG) for 10 minutes followed by an ECG recording during the neurocognitive tasks performed, as outlined in Section 2.4.3. The tasks performed utilised the Cambridge Neuropsychological Test Automated Battery (CANTAB) and tests included were the spatial working memory (SWM) task, attention switching task (AST), rapid visual processing task (RVP), and the spatial span (SSP) task (Cambridge Cognition, 2021).

The ECG was obtained using a FlexComp Infiniti encoder (Thought Technology Ltd, Canada) and an ECG-Flex/Pro amplifier sensor (Thought Technology Ltd, Canada) connected to three electrode leads. BioGraph Infiniti software (T7900) (Thought Technology Ltd, Canada) was used to record and display the ECG wave. All ECG equipment and software listed are shown below in Figure 2.3 (Thought Technology Ltd, Canada). Three lead ECG was used as it provides a rapid and consistent interpretation of the ECG waveform (Murray et al., 1976). This provides a clear QRS wave for subsequent HRV analysis. Additionally, the ECG was sampled at 2048 samples per second for high precision detection of successive heart beats (Berntson et al., 1997).

Figure 2.3 Equipment for Electrocardiogram Recording and Display

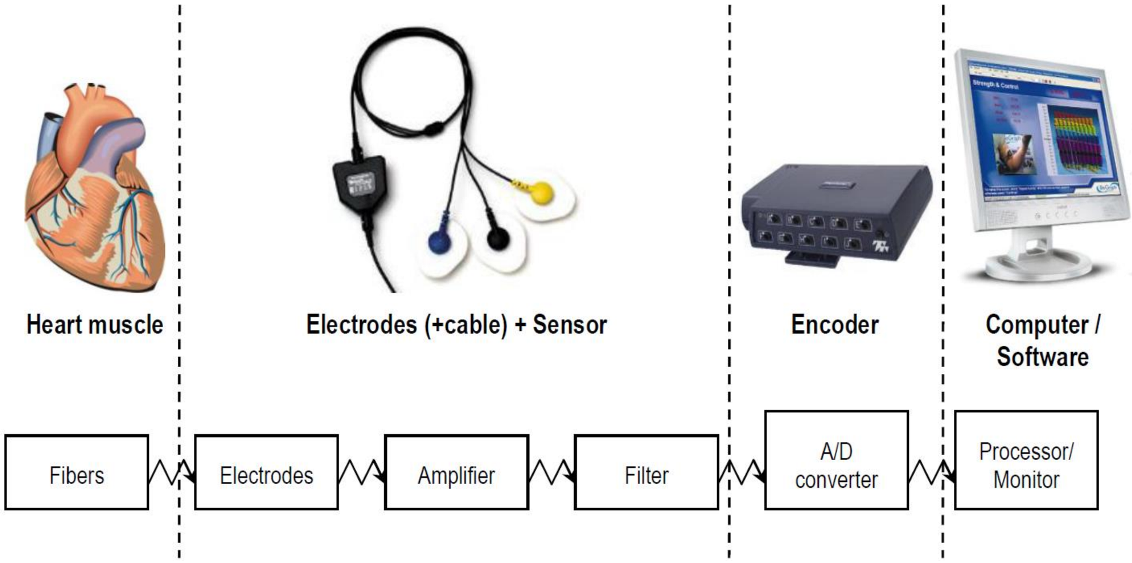


Figure 2.3 illustrates the equipment used for the ECG. The electrodes detect the heart's electrical activity during contraction. It then gets amplified and filtered by the sensor. The encoder converts the analogue signal to a digital signal, which is then sent to the computer. The Biograph Infiniti software allows the processing, recording and display of the ECG data. Image adaption from Combatalade (2010).

Key: A/D converter = Analogue-to-digital converter; ECG = Electrocardiogram; + = and

Prior to placement of the ECG electrodes, as shown in Figure 2.4, the surface of the skin was cleaned using Liv-Wipe (Livingstone International Pty Ltd, Australia) 70% alcohol swabs to decrease dermal interference. The electrodes used were disposable Ag/AgCl ECG electrodes (Red Dot ^{TM}) 2239, USA) and were arranged in an inverted triangle (Combatalade, 2010). The negative (yellow) and ground (black) leads were placed beneath the ends of the right and left clavicle respectively and the positive (blue) lead was placed one to two centimetres below the sternum over the xiphoid process. Further, a screenshot example of a recorded ECG wave is shown in Figure 2.5.

Figure 2.4 Arrangement of Electrocardiogram Electrodes

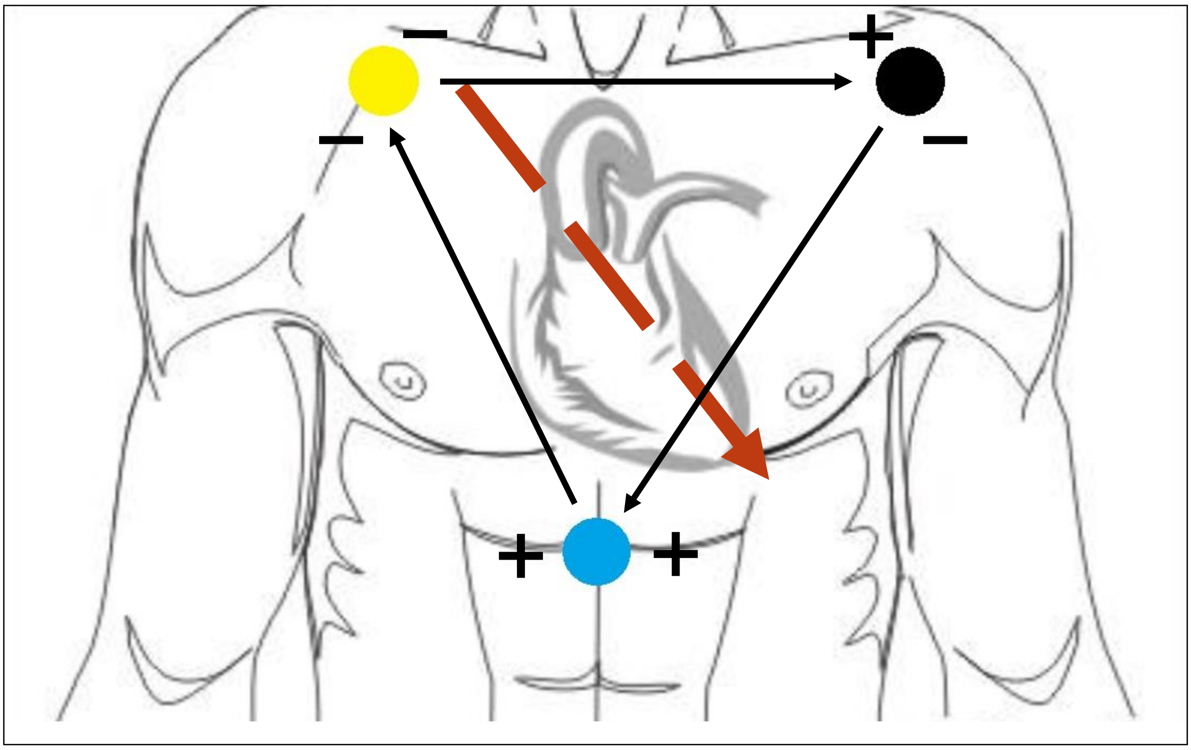


Figure 2.4 demonstrates the triangular position of the electrodes on the chest. The yellow (negative) and black (ground) leads are placed beneath the right and left clavicle and the blue (positive) lead is placed one to two centimetres beneath the sternum. This configuration allows for the positive deflections corresponding to the P, Q, R, S and T waves (Figure 2.5 below). The dashed arrow represents the direction of electrical flow in the heart. Image adapted from Combatalade (2010).

Key: **—>** = Heart's main electrical axis; cm = Centimetre; → = Direction of electrical flow; — = Negative; + = Positive

Figure 2.5 Electrocardiogram Example

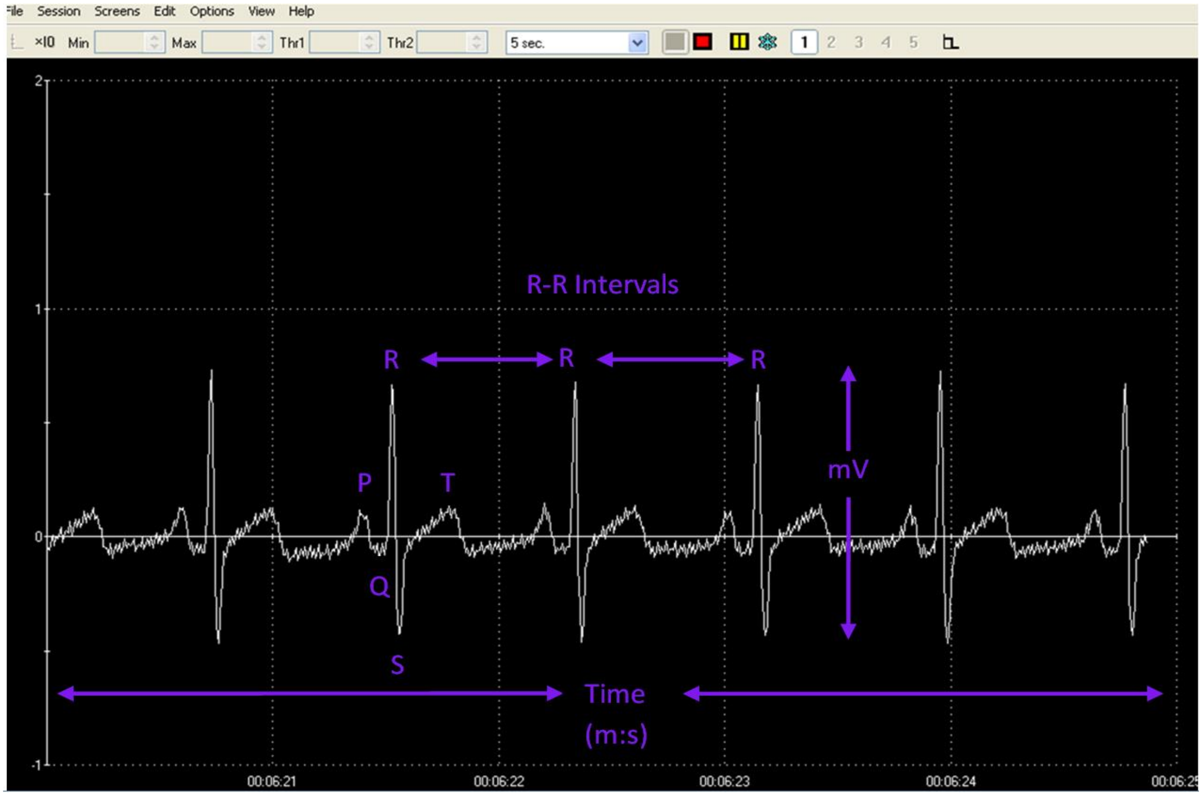


Figure 2.5 depicts a participant's electrocardiogram. It shows millivolts (mV) on the y-axis and time on the x-axis. It is crucial to have well defined R-R intervals to accurately derive heart rate variability.

Key: P = P wave; Q = Q wave; R = R wave; S =S wave; T = T wave; m = Minutes; mV = Millivolts; R-R = Time between successive R waves; s = Seconds

2.4.3 Active Neurocognitive Assessment Tasks

To satisfy the aims of this study, HRV was recorded during several working memory and attention tasks, which are the active phases. These tasks required the participants to navigate touch-screen neurocognitive tests using the Cambridge Neuropsychological Test Automated Battery (CANTAB) (Cambridge Cognition, 2021), all of which are well validated throughout the literature (Matsuura et al., 2014, Makhani et al., 2015, Karagiannopoulou et al., 2016, Waller et al., 2016). The CANTAB is one of the most widely utilised and comprehensive methods of assessment for executive function. Its advantage over other methods is its ability to be utilised on a computer (controlling for variation across examiners), it is non-verbal, and has empirical evidence for prefrontal and medial temporal activation during performance on these tasks (Luciana and Nelson, 2002, Matsuura et al., 2014). The specific tasks administered were as follows:

2.4.3.1 Spatial Working Memory Task

Spatial working memory (SWM) (Gomez et al., 2014, Makhani et al., 2015, Cambridge Cognition, 2021) requires the retention and manipulation of visuospatial information. This has executive function demands and measures strategy as well as errors. The test begins with a small number of coloured boxes on the screen. The participant must find a 'token' within the boxes by a process of elimination. The number of boxes is gradually increased as well as number of tokens that must be found. The colour and position of the boxes change for each trial in order to discourage any search strategies. This test provides twenty-four measures of SWM including errors, strategy, and latency.

Figure 2.6 Spatial Working Memory Task

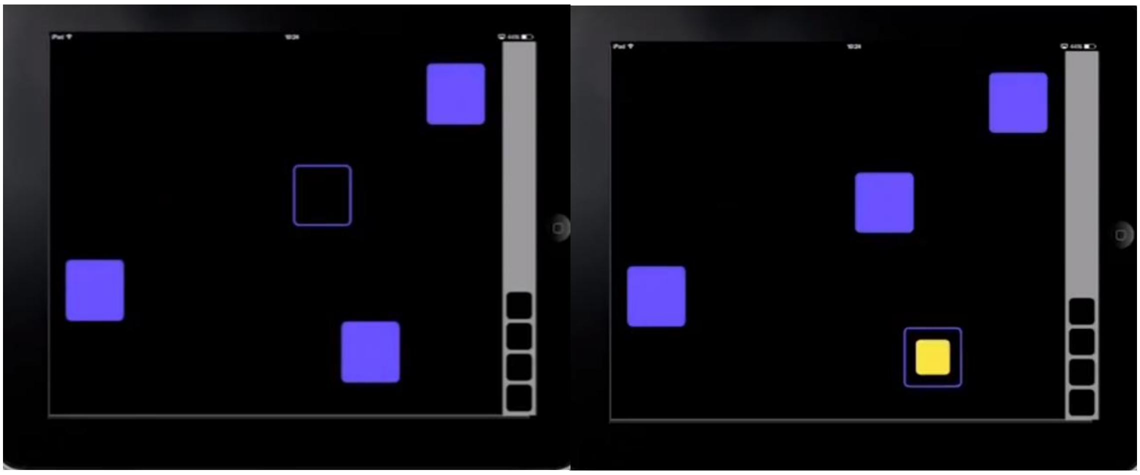


Figure 2.6 shows a screenshot from the spatial working memory task (Gomez et al., 2014, Makhani et al., 2015, Cambridge Cognition, 2021). The participant must select boxes to reveal the ‘token’ behind them. The token changes position but will never be in the same box twice. Therefore, the participant must use a process of elimination to find all tokens. The difficulty increases with the number of boxes and tokens.

2.4.3.2 Spatial Span Task

Spatial span (SSP) (Matsuura et al., 2014, Cambridge Cognition, 2021) is an assessment of working memory capacity. This test begins with white squares, some of which briefly change colour in a variable sequence. The participant must then touch the boxes which changed colour in the same order. The number of boxes increases throughout, and the sequence and colours are varied also. This provides six measures including span length, errors, attempts and latency.

Figure 2.7 Spatial Span Task

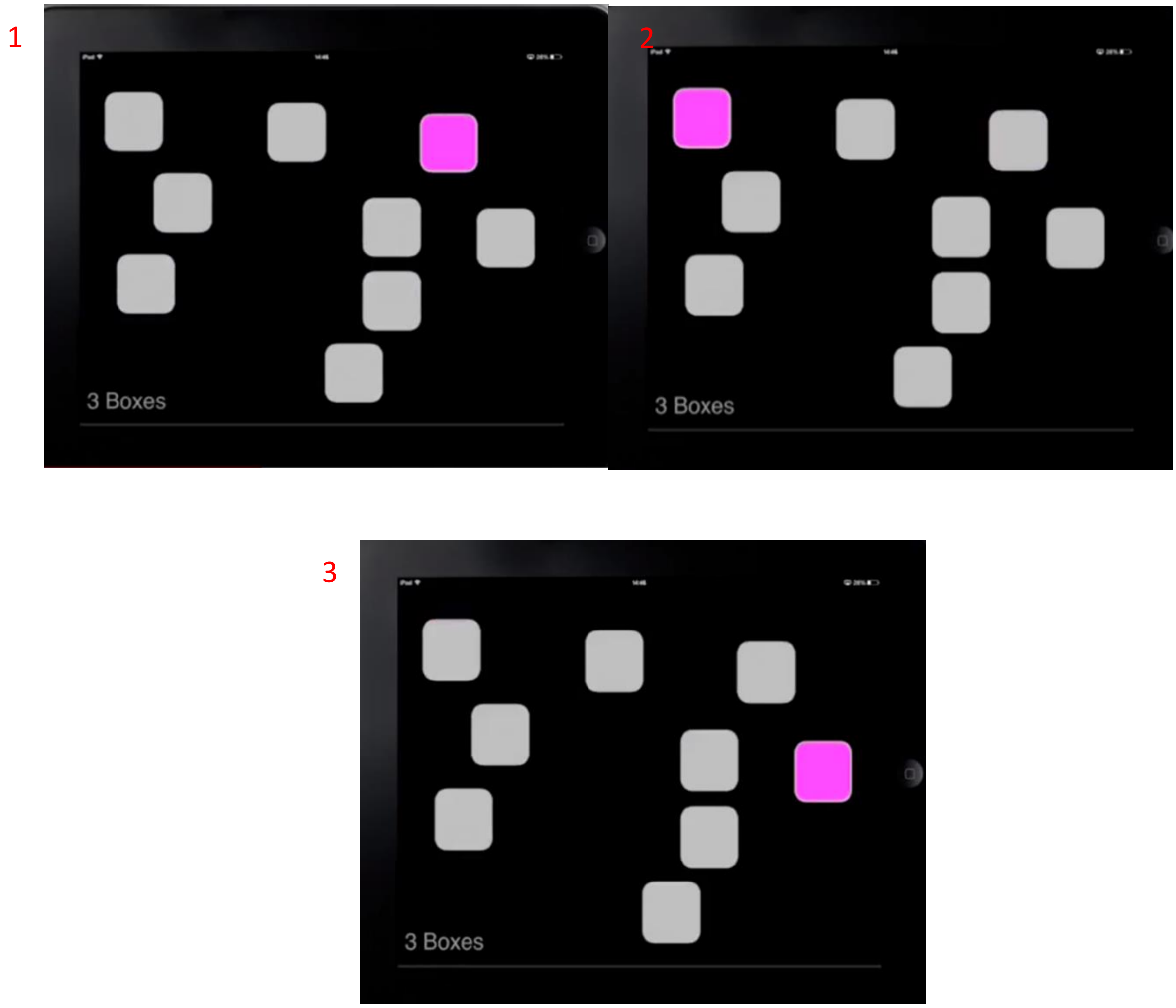


Figure 2.7 shows a snapshot of the spatial span task (Matsuura et al., 2014, Cambridge Cognition, 2021). The boxes will light up one at a time in a particular order and the participant must select the same boxes in the same order without errors. The difficulty is increased with the number of boxes that light up in each pattern. In the example above, only 3 boxes light up in the sequence.

2.4.3.3 Attention Switching Task

Attentional switching task (AST) (Karagiannopoulou et al., 2016, Cambridge Cognition, 2021) is a test of the participant's ability to shift attention between tasks and to ignore irrelevant information during interfering and distracting events. This test is designed to measure top-down cognitive control, which involves the prefrontal cortex (Buschman and Miller, 2007). This test displays an arrow on either side of the screen and can point in any direction. Each trial has a cue which tells the participant to either respond according to the direction of the arrow or the side that the arrow appears on. The AST provides measures including latency and errors, which reflect the ability to shift attention and ignore interference.

Figure 2.8 Attention Switching Task

Figure 2.8 illustrates the attention switching task (Karagiannopoulou et al., 2016, Cambridge Cognition, 2021). An arrow appears on the screen with a cue given at the top. The participant must choose the left or right button depending on which cue is given. They must do this as quickly as they can without error.

2.4.3.4 Rapid Visual Information Processing Task

Rapid visual information processing (RVP) (Waller et al., 2016, Cambridge Cognition, 2021) is a measure of sustained attention. This task requires participants to detect a target sequence of digits. A white box appears in the centre of the screen, inside which, digits from 2-9 appear in pseudo-random order at a rate of 100 digits per minute. The nine outcome measures include latency, probabilities, and sensitivity.

Figure 2.9 Rapid Visual Processing Task

Figure 2.9 shows the rapid visual processing task (Waller et al., 2016, Cambridge Cognition, 2021). Digits are shown in a white box in the centre of the screen and will change at a rate of 100 units per minute. The participant is given a target sequence and once detected they must press the button.

2.4.4 General Health Questionnaire

The General Health Questionnaire (GHQ) was then administered to obtain detailed health data. The GHQ, originally developed by Goldberg (1972), is used as a screening test for non-psychotic illness. The multidimensional focus of this questionnaire allows for the various dimensions of health to contribute to the total score, as the items range from general unwell feelings to that of depression and suicide. Each item consists of a question asking whether the participant has recently experienced a symptom or item of behaviour (e.g., "have you recently been feeling gloomy?"). From a scale stating, 'less than usual', ' no more than usual', 'rather more than usual' and 'much more than usual', each response has a weighting all of which are added to provide a total score for the GHQ.

2.4.5 Final Blood Pressure Recording

Finally, three blood pressure measurements were obtained at the end of the study, using the same procedure as that outlined for pre-study (baseline) BP measurement in Section 2.4.1. The three measurements were averaged for the post-study readings, and this final measure concluded the experimental protocol.

2.4.6 Summary of Experimental Protocol

Figure 2.10 summarises the sequential steps taken to perform the experimental protocol.

Figure 2.10 Present Study Experimental Protocol

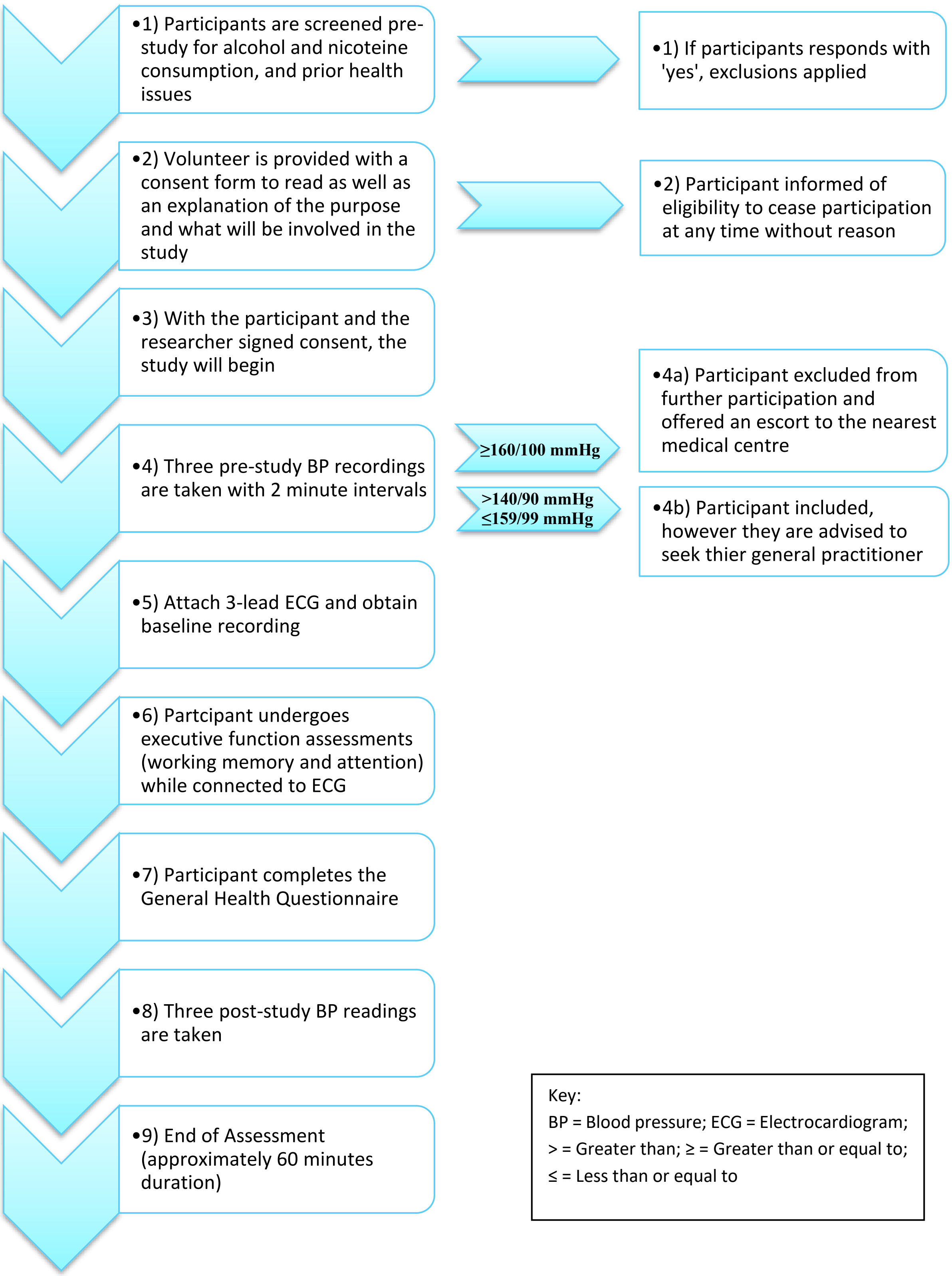


Figure 2.10 summarises the experimental methodology followed by the current study. This study has been approved by the University of Technology Sydney Human Research Ethics Committee.

2.5 Derivation of Heart Rate Variability

The ECG data was collected and stored as a text file containing a time and corresponding millivolts value. The data was pre-processed (Section 2.5.1) using Kubios HRV software (University of Kuopio, Kuopio, Finland), to detect the QRS complex, average heartbeat length, and amplitude threshold. The time at which each R wave occurs was logged to produce HRV time series data. The differences between consecutive R waves were taken to be the RR interval. A power density spectrogram was then derived from the application of the fast Fourier transform. The HRV frequency parameters presented are high frequency (HF) (0.15-0.4Hz) and low frequency (LF) (0.04-0.15Hz). Total power (TP) is the addition of power in each frequency band as well as the very low frequency (VLF) band (TP = VLF (0.01-0.04Hz) +LF + HF). The sympathovagal balance was determined by the ratio of LF/HF*100. Power (ms^2) for each frequency band is calculated as the corresponding area under the curve of the power frequency spectrogram.

HRV data can also provide information on variability as a function of time. Table 2.2 provides the descriptions of the time domain HRV parameters explored in the present study; mean R-R interval, SDNN, RMSSD, and pNN50, as appropriate for a 10-minute electrocardiogram recording.

Table 2.2 Time Domain HRV Parameters

Time Domain Parameter (unit)	Description
Mean R-R Interval (ms)	Mean time between successive R waves
SDNN (ms)	Standard deviation of all NN intervals
RMSSD (ms)	Square root of the mean squared differences of successive NN intervals
pNN50 (%)	NN50 count divided by total number of NN intervals

Table 2.2 shows the time domain HRV parameters used in this study, which are appropriate for a ten-minute electrocardiogram recording. Adapted and modified from the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996).

Key: HRV = Heart rate variability, ms = Milliseconds, NN interval = Consistent consecutive point on electrocardiogram, NN50 = Total number of consecutive NN interval differences >50ms, > = Greater than, % = Percentage

Other geometric and non-linear methods require longer ECG segments of over 10 minutes (e.g., 24hr recording) (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996) and were therefore inappropriate for application in the current analysis. HRV is inherently skewed (Macfarlane, 2011), therefore, to satisfy normal distribution requirements, logarithmic transformations were applied to HRV parameters (HF, LF, LF/HF, TP, RMSSD, and SDNN) prior to analysis.

2.5.1 Beat Detection and Pre-Processing

The ECG data was imported into Kubios HRV software (University of Kuopio, Kuopio, Finland). The R-waves were automatically detected by applying the built-in QRS detection algorithm. This algorithm is based on the Pan-Tomkins algorithm (Pan and Tompkins, 1985). The detector was broken into a pre-processing phase and followed by decision rules phase. The pre-processing included bandpass filtering of the ECG signal (which reduces the power line noise, baseline wander, and other noise components) and squaring the data samples (highlighting peaks, and moving average filtering, which, smooths close-by peaks). The decision rules were the amplitude threshold and comparison to expected value between adjacent R-waves. Artefacts in the time series can significantly distort the HRV analysis results, therefore, artefacts were corrected or removed from analysis.

2.6 Statistical Analysis

All statistical analyses were performed using SPSS Version 22.0 (IBM Corp., 2013, New York, USA) to explore the differences in HRV parameters between baseline and the active tasks within the blue- ($n = 48$) and white-collar ($n = 53$) groups, as well as between the two groups. Associations were also explored within the blue- and white-collar groups.

Data normality was inspected visually and absolute HRV values were normalised via log-transformation. Artefact noise was reduced by removal of outliers (± 3 standard deviations from the mean) (Howell, 1998). Statistical significance was reported at a p-value of < 0.05 and all values are reported to the nearest two decimal places.

2.7 Statistical Methods

2.7.1 Power Analysis

To determine the minimum sample size required to produce statistically reliable data a power analysis was performed (Thomas and Krebs, 1997). Statistical power increases with increasing sample size (Lachin, 1981, Thomas and Krebs, 1997) and based on moderate-large effect, the minimum sample size required for this research was approximately 30 (Cohen, 1988, Cohen, 1992). In groups with n < 30, non-parametric analyses were conducted.

2.7.2 Dependent and Independent Sample t-tests

Dependent sampled (paired) t-tests were applied to establish significant differences between the baseline and active phase (neurocognitive performance tasks: SWM, AST, RVP, and SSP (Cambridge Cognition, 2021)) HRV parameters and between pre- and post-study BP recordings in both the blue- and white-collar groups. Independent sample t-tests were applied to determine differences in data between the blue- and white-collar groups. The t-test analyses the significance and magnitude of differences in the means and standard deviations of normally distributed paired and independent samples (Peacock and Peacock, 2010).

2.7.2.1 Mann-Whitney U Test

A non-parametric equivalent to the independent sample t-test, the Mann-Whitney U test, was used when n < 30 (high HRV group vs low HRV group). High HRV and low HRV groups were determined via a median split (Hansen et al., 2003) which was performed on RMSSD, HF, and LF/HF parameters of HRV. Since these HRV variables are strongly correlated (Thayer et al., 2000) a median split was performed on all 3 HRV parameters

(RMSSD, HF, and LF/HF HRV), even though previous authors only perform splits on one HRV variable (RMSSD) (Hansen et al., 2003).

As shown in Section 6.1 (Table 6.1 and Table 6.2), for log RMSSD the white-collar workers had a median of 6.69ms (high group: n = 20, low group: n = 28) and the blue-collar workers also had a median of 6.69ms (high group: n = 24, low group: n = 29). For log HF HRV, the white-collar group had a median of 5.07ms^2 (high group: n = 24, low group: n = 24) and the blue-collar group had a median of 4.62ms^2 (high group: n =26, low group: n = 27). For log LF/HF HRV the white-collar group had a median of 1.49 (high group: n = 24, low group: n = 24) and the blue-collar group had a median of 1.83 (high group: n = 25, low group: n = 28).

This compares the dependent variable based on ranked data between unpaired groups (Lund Research, 2021). This test was used to compare the neurocognitive test scores between the high HRV groups and low HRV groups within the white- and blue-collar workers.

2.7.3 Partial Pearson's Correlation

Partial Pearson's correlation was used to determine the relationship between neurocognitive performance and HRV. Partial Pearson's correlation identifies the strength and direction of a linear relationship between two variables in a sample while controlling for confounders that may influence the parameters in question (Lund Research Ltd, 2020). Validity of the test requires at least one variable to be normally distributed (Peacock and Peacock, 2010).

The r (rho) value, produced from this correlation ranges from r = 1 to r = -1 (Peacock and Peacock, 2010). This specifies the strength of the positive or negative association of the relationship (Peacock and Peacock, 2010). An r = 1 indicates a direct relationship, meaning that as one variable increases so does the other, whereas an r = -1 indicates an inverse relationship, whereby as one variable increases the other decreases by the same amount (Peacock and Peacock, 2010). The sample size is directly related to the r value, whereby, the larger the sample the weaker the r value required to determine statistical significance. An r value of ± 0.1 - 0.3 = weak correlation, ± 0.3 - 0.5 = moderate correlation, and > 0.5 / < -0.5 = strong correlation (Cohen, 1988).

Partial Pearson's correlation was performed while controlling for confounders that are known to influence HRV (education, age, and gender) (Karmali et al., 2017).

2.7.3.1 Partial Spearman's Rank-Order Correlation

The non-parametric alternative to a partial Pearson's correlation used in this study was the partial Spearman's rank-order correlation. This was performed when variables were significantly correlated to covariates (education, BMI, age, and gender). Similar to a partial Pearson's correlation, it produces an r coefficient and p-value to provide the strength and direction of an association while controlling for a covariate (Lund Research, 2021). This test was applied to test groups with small sample size (n < 30) (high HRV and low HRV groups for blue- and white-collar workers).

2.7.4 Bonferroni Correction

Bonferroni corrections were applied in all instances where two or more independent variables were correlated to one dependent variable. This technique makes the p-value more conservative by dividing it by the number of variables, reducing the risk of type 1 errors (i.e., false positives) (Bland and Altman, 1995). In the instance that three or more independent variables were significantly correlated to a dependent variable, to be included in the linear regression model, the result was required to fall at equal to or below the adjusted Bonferroni p-value. Correlations that did not fall equal to or below were still displayed in data tables but were not included in the linear regression model.

2.7.5 Regression Analysis

Linear regression analysis was applied to determine the most significant predictor of HRV with cognitive performance. Subsequent to partial Pearson's correlations, dependent variables correlated with three or more independent variables were then subjected to a linear regression model to identify the strongest predictor(s) of cognitive function. The regression analysis examines the nature of a linear relationship between variables. The coefficient, r^2, determined by a regression outlines how much variance in one variable can be explained by another variable (Lund Research, 2021).

Chapter 3 HRV and Neurocognitive Performance (White-Collar Workers)

3.1 Results: White-Collar Workers

This chapter will initially report the descriptive statistics relating to the white-collar worker group, followed by the results of neurocognitive performance and HRV for the white-collar sample group. A total of 48 white-collar volunteers with no chronic illnesses, aged 40 ± 11 years, were recruited for the present study. As reported in the Methods (Section 2.7.1), the sample power is adequate for the analyses presented below.

Figure 3.1 shows the sample distribution by position and field. The current sample of white-collar workers were required to be full-time employees and were recruited from sectors including Law, Accounting, Banking, Finance, Building Management, Real Estate, and Asset Management.

Figure 3.1 White-Collar Sample Distribution by Position and Field (n = 48)

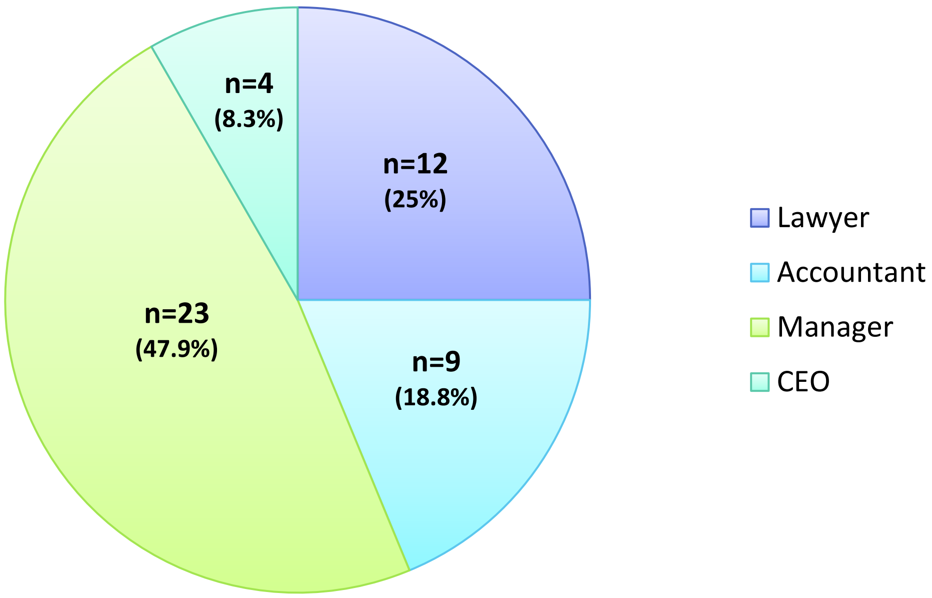


Figure 3.1 displays the breakdown of white-collar workers, by position, included in this study. This sample included 12 lawyers, 9 accountants, and 23 executives from, finance, real estate, and asset management.

Key; CEO = Chief executive officer; n = Sample size

3.1.1 Demographics

Demographic data (mean ± SD) for the total white-collar population are provided in Table 3.1. The white-collar participants were aged between 23-61 years old, with a mean age of 39.83 ± 11 years. This sample comprised of 25 males (52%) and 23 females (48%) with a mean BMI of 23.54 ± 2.4. The normal range of BMI is indicated to be between 19-25 (Garrouste-Orgeas et al., 2004). The mean years of education was 4.33 ± 1.2, and they had a mean General Health Questionnaire (GHQ) score of 6.88 ± 2.08, which fell below the threshold. For the GHQ, 30 is the maximum score and the threshold for poor psychological wellbeing is 12 (Goldberg, 1972). Higher scores indicate increased risk of mental illness (Goldberg and Williams, 2006).

Table 3.1 Mean Demographics for the White-collar Worker Sample Population (n = 48)

Demographic	Mean ± SD
Years of Age	39.83 ± 10.98
Male (n; %) **Female (n; %)**	n = 25 (52%) n = 23 (48%)
BMI	23.54 ± 2.4
Years of Education	4.33 ± 1.2
GHQ Score	6.88 ± 2.08

Table 3.1 shows the mean demographic scores for the white-collar workers sample (n = 48). The normal BMI reference range is 19-25 (Garrouste-Orgeas et al., 2004). The maximum score for the GHQ is 30 with a threshold of 12 (Goldberg, 1972). Higher scores indicate increased risk of mental illness (Goldberg and Williams, 2006).

Key: BMI = Body mass index; GHQ = General health questionnaire (Goldberg, 1972); n = Sample size; SD = Standard deviation; % = Percentage

3.1.2 Neurocognitive Performance Measures

Outcome measures (mean ± SD) from the neurocognitive performance tasks, Spatial Working Memory (SWM), Attention Switch task (AST), Rapid Visual Processing (RVP), and Spatial Span (SSP) task are displayed in Table 3.2.

Some large variances were observed in the current findings. Despite the fact that the Cambridge Neuropsychological Test Automated Battery (CANTAB) tests have shown strong correlations with traditional executive tasks (e.g., Wechsler adult intelligence scale (Wechsler, 1997)), the correlations show less consistency when controlling for education and age (Smith et al., 2013). Furthermore, executive function tests which have been strongly validated may not necessarily correlate (Golden et al., 1998, Miller et al., 2009). Therefore, some of the variation observed in the data may be explained by the underlying mechanisms being tested (e.g., working memory) since test-retest variability in neurocognitive functions is known to be common (Luciana, 2003).

Spatial Working Memory

Strategy is the first measure obtained in the SWM task. This was determined by the number of times the participant initiated the search from a new position. As this test is performed through a process of elimination, a higher result indicates less strategy as the participant is using chance to find the token. The white-collar workers started from a new position 5.73 ± 2.63 times.

The additional measures in this test were the number of errors made. Specifically, these were the errors made in the 4-box trial (0.29 ± 0.58), the 6-box trial (1.63 ± 1.92), the 8-box trial (2.75 ± 2.50), and the total errors made over all trials (4.67 ± 3.74).

Attention Switching Task

The AST measured congruent (2.38 ± 2.37) and incongruent errors (8 ± 3.14), errors made on the “arrow” cue (4.71 ±2.68) and “side” cue (4.33 ± 2.56), and the total correct responses (144.21 ± 8.53). The AST also measured reaction time for different aspects of the test including the “direction” cue (658.14 ± 218.13 ms), “side” cue (602 ±208.19 ms), all incongruent cues (691.25 ± 260.28 ms), and all correct trials (581.19 ± 209.41 ms).

Rapid Visual Processing

The RVP task measured the ability to detect the signals (0.90 ± 0.08), reaction time (432.22 ± 47.31 ms), and the number of sequences that were detected (35.79 ± 13.36) and missed (18.21 ± 13.36).

Spatial Span

Finally, the SSP task measured the longest sequence remembered (7.92 ± 1.07) and the errors made. These errors consisted of selecting a box that was not next in the sequence (13.48 ± 5.65) and selecting boxes that were not in the sequence at all (1.58 ± 1.43).

Table 3.2 Mean Neurocognitive Performance Measures for the White-collar Worker Group (n = 48)

Neurocognitive Task	Measure	Mean ± SD
Spatial Working Memory	Strategy	5.73 ± 2.63
	Total Errors	4.67 ± 3.74
	Errors 4 boxes	0.29 ± 0.58
	Errors 6 boxes	1.63 ± 1.92
	Errors 8 boxes	2.75 ± 2.50
Attention Switching Task	Congruent Errors	2.38 ± 2.37
	Arrow Errors	4.71 ±2.68
	Incongruent Errors	8 ± 3.14
	Latency (direction cue) (ms)	658.14 ± 218.13
	Latency (incongruent cue) (ms)	691.25 ± 260.28
	Latency (all correct trials) (ms)	581.19 ± 209.41
	Latency (side cue) (ms)	602 ±208.19
	Side Errors	4.33 ± 2.56
	Total Correct	144.21 ± 8.53
	Total Incorrect	10.5 ± 6.00
Rapid Visual Processing	Signal Detection	0.90 ± 0.08
	Reaction Time (correct) (ms)	432.22 ± 47.31
	Total Sequences Detected	35.79 ± 13.36
	Total Sequences Missed	18.21 ± 13.36
Spatial Span	Longest Sequence	7.92 ± 1.07
	Errors (not next in sequence)	13.48 ± 5.65
	Errors (not in sequence at all)	1.58 ± 1.43

Table 3.2 shows the mean ± SD for the neurocognitive tasks (SWM, AST, RVP, SSP) for the white-collar worker group (n = 48).

Key: ms = Milliseconds; n = Sample size; SD = Standard deviation

3.1.3 Heart Rate Variability Parameters

The values (mean ± SD) for baseline heart rate variability frequency and time parameters for the white-collar group are displayed in Table 3.3 below. Logarithmic transformations were applied to reduce the effect of skewed HRV data (Tarvainen et al., 2009). The logarithmically-transformed HRV data was subsequently used for further statistical analysis.

Table 3.3 shows the average HRV values taken at rest and, henceforth will be referred to as baseline data. All HRV data obtained during active tasks (the neurocognitive tasks) (Table 3.4, 3.5, 3.6, 3.7) were compared to the baseline HRV data (Table 3.3). Data are reported as active minus baseline (denoted: cardiac reactivity) and subsequently, all significant results are presented as a summary table in Section 3.1.4 (Table 3.8).

Table 3.3 Mean Baseline HRV Parameters White-collar Group (n = 48)

HRV State		HRV Parameter	Mean ± SD
Baseline	Frequency Domains	Low Frequency (ms^2)	633.01 ± 178.13
		High Frequency (ms^2)	341.54 ± 494.83
		LF/HF	4.30 ± 2.42
		Total Power (ms^2)	1099.821 ± 621.41
		Log Low Frequency (ms^2)	6.41 ± 0.28
		Log High Frequency (ms^2)	5.23 ± 0.95
		Log LF/HF	1.18 ± 0.89
		Log Total Power (ms^2)	6.88 ± 0.48
	Time Domains	Mean RR (ms)	818.36 ± 43.15
		SDNN (ms)	34.68 ± 10.47
		RMSSD (ms)	26.17 ± 14.23
		pNN50 (%)	4.80 ± 1.37
		Log RMSSD (ms)	6.71 ± 3.76
		Log SDNN (ms)	3.51 ± 2.58

Table 3.3 reports the baseline values for frequency and time domains of heart rate variability parameters in the white-collar worker group (n = 48).

Key: HRV = Heart rate variability; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = Percentage of NN (beat to beat) intervals greater than 50 milliseconds; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); % = Percentage

HRV parameters (mean ± SD) and cardiac reactivity data for HRV frequency and time domain parameters are reported for all executive function tasks: Spatial Working Memory (SWM) (Table 3.4), Attention Switching task (AST) (Table 3.5), Rapid Visual Processing (RVP) (Table 3.6), and the Spatial Span (SSP) task (Table 3.7).

Dependent sample t-tests were used to determine any changes from baseline that were significantly different. These are highlighted in red throughout the tables below and reported collectively as a summary in Table 3.8.

HRV parameters (mean ± SD) during the spatial working memory (SWM) task are shown in Table 3.4 with comparisons to the baseline HRV data presented in Table 3.3. Significant increases were observed in log LF/HF from baseline (1.18 ± 0.89) to active (1.61 ± 0.82) phase, and log RMSSD baseline (6.71 ± 3.76 ms) to active phase (6.73 ± 4.04 ms). A significant reduction was found in log HF from baseline (5.23 ± 0.95 ms^2) to active phase (4.75 ± 0.68 ms^2).

Table 3.4 Mean HRV during the Spatial Working Memory Task in the White-collar Worker Group (n = 48)

HRV State		HRV Parameter	Mean ± SD	Cardiac Reactivity (Mean ± SD)	t	df	p
SWM	Frequency Domains	LF (ms^2)	672.67 ± 445.18	39.66 ± 526.54	-0.52	47	0.61
		HF (ms^2)	154.86 ± 158.27	-186.68 ± 433.23	2.954	47	0.005
		LF/HF	6.60 ± 4.52	2.31 ± 4.05	-3.91	47	0.00
		TP (ms^2)	930.55 ± 751.68	-169.28 ± 870.29	1.33	47	0.19
		Log LF (ms^2)	6.33 ± 0.6	-0.08 ± 0.74	0.8	47	0.43
		Log HF (ms^2)	4.75 ± 0.68*	-0.48 ± 0.77	4.30	47	<0.001
		Log LF/HF	1.61 ± 0.82*	0.42 ± 0.66	-4.45	47	<0.001
		Log TP (ms^2)	6.70 ± 0.52	-0.18 ± 0.75	1.65	47	0.11
	Time Domains	Mean RR (ms)	833.75 ± 56.74	15.38 ± 29.48	-3.58	47	0.001
		SDNN (ms)	34.60 ± 13.26	-0.09 ± 15.58	0.04	47	0.97
		RMSSD (ms)	28.98 ± 22.78	2.80 ± 23.92	-0.8	47	0.43
		pNN50 (%)	3.12 ± 5.99	1.18 ± 5.48	2.602	47	0.012
		Log RMSSD (ms)	6.73 ± 4.04*	0.02 ± 0.04	-3.35	46	0.002
		Log SDNN (ms)	3.48 ± 2.58	-0.03 ± 0.41	0.48	46	0.64

Table 3.4 shows the mean HRV and cardiac reactivity during the Spatial Working Memory task for the white-collar worker group (n = 48). Red asterisks signify significant differences (p < 0.05) from baseline.

Key: df = Degrees of freedom; HF = High Frequency; HRV = Heart rate variability; LF = Low Frequency; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = Percentage of NN (beat to beat) intervals greater than 50 milliseconds; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); SWM = Spatial working memory; TP = Total power; t = T statistic; % = Percentage; * = p = Level of statistical significance (< 0.05); < = Less than

HRV parameters (mean ± SD) during the attention switching task (AST) are shown in Table 3.5. During the AST, a significant reduction was found in log LF between the baseline (Table 3.3) (6.41 ± 0.28 ms^2) and active phase (6.27 ± 0.35 ms^2).

Table 3.5 Mean HRV during the Attention Switching Task for the White-collar Worker Group (n = 48)

HRV State		HRV Parameter	Mean ± SD	Cardiac Reactivity (Mean ± SD)	t	df	p
AST	Frequency Domains	LF (ms^2)	563.71 ± 242.45	-69.31 ± 255.87	1.86	47	0.07
		HF (ms^2)	250.94 ± 158.27	-90.60 ± 715.20	0.87	47	0.39
		LF/HF	4.49 ± 2.2	0.19 ± 2.19	-0.91	47	0.55
		TP (ms^2)	930.54 ± 535.12	-156.79 ± 769.44	1.4	47	0.17
		Log LF (ms^2)	6.27 ± 0.35*	-0.14 ± 0.40	2.52	47	0.02
		Log HF (ms^2)	4.93 ± 0.83	-0.30 ± 1.21	1.69	47	0.1
		Log LF/HF	1.34 ± 0.65	0.15 ± 0.90	-1.16	47	0.25
		Log TP (ms^2)	6.71 ± 0.45	-0.16 ± 0.58	1.96	47	0.06
	Time Domains	Mean RR (ms)	823.06 ± 57.67	4.70 ± 33.15	-0.97	47	0.34
		SDNN (ms)	33.16 ± 15.70	-1.52 ± 13.43	0.78	47	0.44
		RMSSD (ms)	28.41 ± 26.10	2.23 ± 29.27	-0.52	47	0.61
		pNN50 (%)	3.14 ± 4.52	1.63 ± 4.01	1.68	47	0.1
		Log RMSSD (ms)	6.71 ± 4.04	0.00 ± 0.04	-6.43	47	0.52
		Log SDNN (ms)	3.43 ± 2.75	-0.07 ± 0.34	1.51	47	0.14

Table 3.5 shows the mean HRV and cardiac reactivity during the Attention Switching task for the white-collar group (n = 48). Highlighted in red with an asterisk signifies significant differences ($p < 0.05$) from baseline.

Key: AST = Attention switching task; df = Degrees of freedom; HF; High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = Percentage of NN (beat to beat) intervals greater than 50 milliseconds; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); t = T statistic; TP = Total power; % = Percentage; * = p = Level of statistical significance (< 0.05)

HRV parameters (mean ± SD) during the rapid visual processing (RVP) task are shown in Table 3.6 with comparisons made to baseline data (Table 3.3). The RVP task showed significant reductions in log LF from baseline (6.41 ± 0.28 ms^2) to active (6.15 ± 0.46 ms^2), log TP from baseline (6.88 ± 0.48 ms^2) to active (6.61 ± 0.43 ms^2), and log SDNN baseline (3.54 ± 2.58 ms) to active (3.38 ± 2.19 ms).

Table 3.6 Mean HRV during the Rapid Visual Processing Task for the White-collar Worker Group (n = 48)

HRV State		HRV Parameter	Mean ± SD	Cardiac Reactivity (Mean ± SD)	t	df	p
RVP	Frequency Domains	LF (ms^2)	518.04 ± 230.92	-125.77 ± 321.92	2.438	46	0.02
		HF (ms^2)	184.03 ± 126.43	-161.34 ±463.03	2.357	46	0.02
		LF/HF	7.61 ± 26.75	3.31 ± 26.63	-0.85	46	0.4
		TP (ms^2)	796.19 ± 356.05	-303.63 ± 672.75	3.094	47	0.003
		Log LF (ms^2)	6.15 ± 0.46*	-0.51 ± 1.35	3.12	45	0.003
		Log HF (ms^2)	5.04 ± 0.61	-0.21 ± 1.20	1.53	45	0.13
		Log LF/HF	1.17 ± 0.49	-0.02 ± 0.87	-0.12	45	0.91
		Log TP (ms^2)	6.61 ± 0.43*	-0.40 ± 1.23	2.06	46	0.006
	Time Domains	Mean RR (ms)	823.29 ± 57.33	4.43 ± 40.28	-0.75	46	0.46
		SDNN (ms)	30.33 ± 6.31	-4.35 ± 12.97	2.57	46	0.01
		RMSSD (ms)	23.73 ± 7.75	-2.44 ± 12.95	1.34	46	0.19
		pNN50 (%)	3.69 ± 9.94	1.1 ± 3.88	1.94	46	0.06
		Log RMSSD (ms)	6.71 ± 4.05	0.004 ± 0.063	-0.39	46	0.7
		Log SDNN (ms)	3.38 ± 2.19*	-0.16 ± 0.29	2.96	46	0.005

Table 3.6 shows the mean HRV and cardiac reactivity during the Rapid Visual Processing task for the white-collar worker group (n = 48). Highlighted in red with an asterisk signifies significant differences ($p < 0.05$) from baseline.

Key: df = Degrees of freedom; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = Percentage of NN (beat to beat) intervals greater than 50 milliseconds; RVP = Rapid visual processing; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); t = T statistic; TP = Total power; % = Percentage; * = p = Level of statistical significance (< 0.05)

HRV parameters (mean ± SD) for the spatial span (SSP) task are shown in Table 3.7 with comparisons made to baseline HRV data (Table 3.3). During the SSP, there was a significant increase in log LF/HF from baseline (1.18 ± 0.89) to active (1.59 ± 0.47). Significant reductions were observed in log HF between baseline (5.23 ± 0.95 ms^2) and active (4.81 ± 0.57 ms^2), and log TP baseline (6.88 ± 0.48 ms^2) and active (6.75 ± 0.36 ms^2).

Table 3.7 Mean HRV during the Spatial Span Task for the White-collar Worker Group (n = 48)

HRV State		HRV Parameter	Mean ± SD	Cardiac Reactivity (Mean ± SD)	t	df	p
SSP	Frequency Domains	LF (ms^2)	647.55 ± 244.93	14.54 ± 264.99	-0.25	46	0.80
		HF (ms^2)	148.87 ± 119.78	-192.67 ± 449.12	2.97	46	0.005
		LF/HF	5.42 ± 2.20	1.12 ± 3.14	-2.7	46	0.01
		TP (ms^2)	893.54 ± 349.31	-206.28 ± 522.58	2.71	47	0.009
		Log LF (ms^2)	6.40 ± 0.41	-0.15 ± 0.96	0.38	46	0.71
		Log HF (ms^2)	4.81 ± 0.57*	-0.52 ± 1.03	3.40	46	0.001
		Log LF/HF	1.59 ± 0.47*	0.37 ± 0.94	-3.25	46	0.002
		Log TP (ms^2)	6.75 ± 0.36*	-0.26 ± 0.99	2.06	46	0.046
	Time Domains	Mean RR (ms)	817.85 ± 55.12	-0.51 ± 39.62	0.18	46	0.86
		SDNN (ms)	35.59 ±13.95	0.91± 8.93	-0.53	46	0.602
		RMSSD (ms)	28.45 ± 21.81	2.28 ± 21.87	-0.63	46	0.54
		pNN50 (%)	3.05 ± 6.94	-1.75 ± 4.24	1.5	46	0.14
		Log RMSSD (ms)	6.71 ± 4.01	0.02 ± 0.04	0.41	46	0.69
		Log SDNN (ms)	3.57 ± 2.64	-0.06 ± 0.51	-0.08	46	0.96

Table 3.7 shows the mean HRV and cardiac reactivity during the Spatial Span task for the white-collar worker group (n = 48). Highlighted in red with an asterisk signifies significant differences ($p < 0.05$) from baseline.

Key: df = Degrees of freedom; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = percentage of NN (beat to beat) intervals greater than 50 milliseconds; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span; t = T statistic; TP = Total power; % = Percentage; * = p = Level of statistical significance (< 0.05)

3.1.4 Summary of Heart Rate Variability Findings

Dependent sample t-tests were performed, to determine significant differences between baseline and active (neurocognitive task) HRV measures as reported above. A summary of all significant findings for the white-collar workers are displayed in Table 3.8.

Throughout the SWM task, significant increases were observed in log LF/HF (baseline 1.18 ± 0.89; active 1.61 ± 0.82), and log RMSSD (baseline 6.71 ± 3.76 ms; active 6.73 ± 4.04 ms). However, significant reductions were found in log HF (baseline 5.23 ± 0.95 ms^2; active 4.75 ± 0.68 ms^2).

During the AST significant reductions were found in log LF (baseline 6.41 ± 0.28 ms^2; active 6.27 ± 0.35 ms^2).

Within the RVP task reductions were seen in log LF (baseline 6.41 ± 0.28 ms^2; active 6.15 ± 0.46 ms^2), log TP (baseline 6.88 ± 0.48 ms^2; active 6.61 ± 0.43 ms^2), and log SDNN (baseline 3.54 ± 2.58 ms; active 3.38 ± 2.19 ms).

Finally, the SSP task saw a significant increase in log LF/HF (baseline 1.18 ± 0.89; active 1.59 ± 0.47). Significant reductions were observed in log HF (baseline 5.23 ± 0.95 ms^2; active 4.81 ± 0.57 ms^2), and log TP (baseline 6.88 ± 0.48 ms^2; active 6.75 ± 0.36 ms^2).

Table 3.8 Dependent Sample t-test between Baseline and Active HRV in the White-collar Worker Group (n = 48)

Task	Variable	t	df	p	Baseline mean ± SD	Active mean ± SD	Mean difference (active-baseline)
SWM	Log HF (ms^2)	4.30	47	0.000	5.23 ± 0.95	4.75 ± 0.68	-0.48
	Log LF/HF	-4.45	47	0.000	1.18 ± 0.89	1.61 ± 0.82	0.43
	Log RMSSD (ms)	-3.35	46	0.002	6.71 ± 3.76	6.73 ± 4.04	0.02
AST	Log LF (ms^2)	2.52	47	0.02	6.41 ± 0.28	6.27 ± 0.35	-0.14
RVP	Log LF (ms^2)	3.12	45	0.003	6.41 ± 0.28	6.15 ± 0.46	-0.26
	Log TP (ms^2)	2.86	46	0.006	6.88 ± 0.48	6.61 ± 0.43	-0.27
	Log SDNN (ms)	2.96	46	0.005	3.54 ± 2.58	3.38 ± 2.19	-0.16
SSP	Log HF (ms^2)	3.40	46	0.001	5.23 ± 0.95	4.81 ± 0.57	-0.42
	Log TP (ms^2)	2.06	46	0.046	6.88 ± 0.48	6.75 ± 0.36	-0.13
	Log LF/HF	-3.25	46	0.002	1.18 ± 0.89	1.59 ± 0.47	0.41

Table 3.8 displays the significant results from dependent sample t-tests between baseline and active (neurocognitive performance task) HRV states for the white-collar worker group (n = 48).

Key: AST = Attention switching task; df = Degrees of freedom; HF = High frequency; LF = Low frequency; LF/HF = Low frequency divided by high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; p = Level of statistical significance ($p < 0.05$); RMSSD = Root mean squared of successive differences; RVP = Rapid visual processing; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span; SWM = Spatial working memory; t = T statistic; TP = Total power

3.1.5 Correlations between Neurocognitive Performance and HRV

All data has been corrected for the confounders, including partial Pearson's correlations being performed to determine correlations between HRV and the neurocognitive performance measures for the white-collar group (Table 3.9). Correlation graphs for the white-collar group are displayed in Figure 3.2 and Figure 3.3.

Attention Switching Task

Partial correlations during the AST showed log LF/HF was negatively associated to the errors made when the "side" cue was given whilst controlling for Age (r = -0.306, p = 0.04), and log TP was also negatively correlated to reaction time when controlling for BMI (r = -0.299, p=0.04).

Spatial Span Task

During the SSP task, log RMSSD was negatively associated to the total errors made while controlling for Education (r = -0.295, p = 0.045).

Table 3.9 Partial Pearson's Correlation between HRV and Neurocognitive Performance in the White-collar Worker Group (n = 48)

Task	Covariate	Dependent Variable	Independent Variable	r	p
AST	Age (years)	Log LF/HF	Errors (side)	-0.306	0.04
	BMI	Log TP	Reaction Time (incongruent)	-0.299	0.04
SSP	Education (years)	Log RMSSD	Errors Made	-0.295	0.045

Table 3.9 displays the significant results from a partial Pearson's correlation between HRV and the cognitive performance scores in the white-collar group (n = 48).

Key: AST = Attention switching task; BMI = Body mass index; HRV = Heart rate variability; LF/HF = Low frequency divided by high frequency; p = Level of statistical significance ($p < 0.05$); r = Correlation coefficient; RMSSD = Root mean squared of successive differences; SSP = Spatial span task; TP = Total power

Correlation graphs are displayed for the white-collar group in Figure 3.2 and Figure 3.3. Figure 3.2 shows an inverse association that exists between log LF/HF and the errors made during the AST (r = -0.306, p = 0.04). This indicates that as the number of errors (side cue) made increases, the LF/HF ratio (sympathovagal balance) decreases and tips in favour of sympathetic dominance.

Figure 3.3 illustrates an inverse association between log RMSSD (parasympathetic activity) and errors made during the SSP task (r = -0.295, p = 0.045), indicating that as the number of errors (total) increased, parasympathetic activity decreased.

Figure 3.2 Correlation between Log LF/HF and Errors for the White-Collar Workers (n = 48)

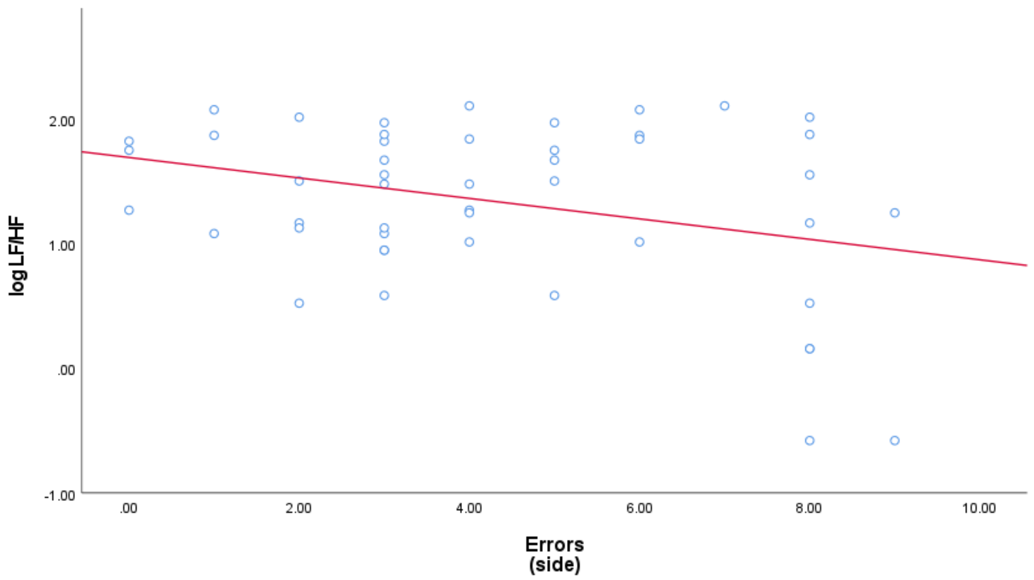


Figure 3.2 displays an inverse association between log LF/HF and the number of errors made during the AST (r = -0.306, p = 0.04) for the white-collar workers (n = 48).

Key: AST = Attention switching task; LF/HF; Low frequency to high frequency ratio; n = Sample size; p = Level of statistical significance (< 0.05); r = Correlation coefficient

Figure 3.3 Correlation between Log RMSSD and Total Errors for the White-Collar Workers (n = 48)

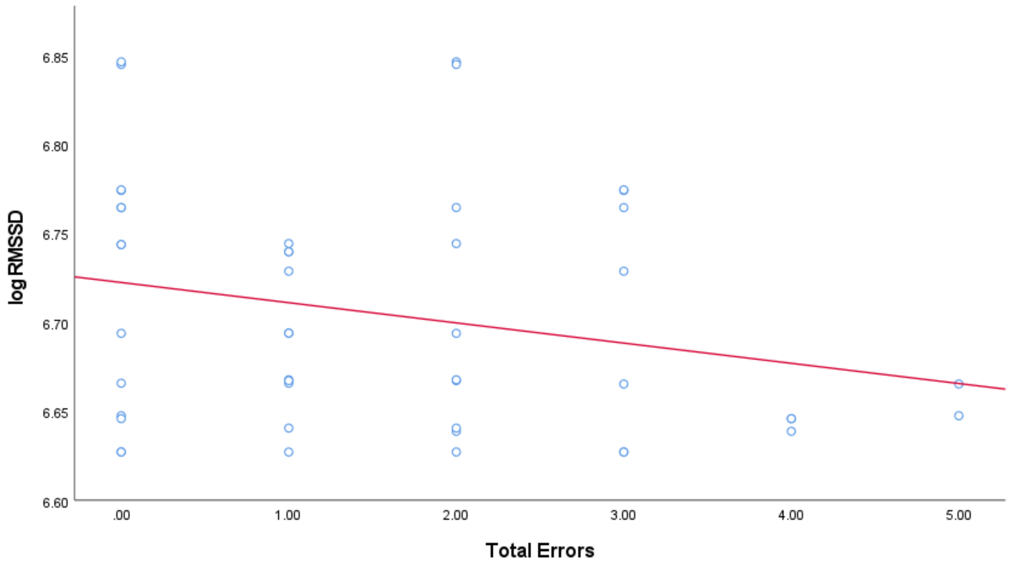


Figure 3.3 displays an inverse relationship between log RMSSD and total errors during the SSP task (r = -0.295, p = 0.045) for the white-collar workers (n = 48).

Key: n = Sample size; p = Level of statistical significance (< 0.05); RMSSD = Root mean squared of successive differences; SSP = Spatial span task

3.2 Discussion: White-Collar Workers

The present chapter aimed to investigate differences in, and associations between, heart rate variability (HRV) parameters and neurocognitive performance within the white-collar workforce sample (Chapter 1.7, Aim 1 and 2). The hypotheses posed (Chapter 1.8, Hypotheses 1 and 2) were accepted with the observation of differences in HRV between the baseline and active (neurocognitive tasks) phases, and associations between HRV and neurocognitive performance measures being detected.

This chapter will also discuss the findings related to HRV parameters and neurocognitive performance, with respect to the white-collar group (n = 48), observed during the different neurocognitive tasks (spatial span (SSP), attention switching task (AST), rapid visual processing (RVP), and spatial working memory (SWM)) (Cambridge Cognition, 2021).

Throughout the literature, a general pattern of HRV effects has emerged such that higher resting HRV has been reported to reflect better adaptability, health, and performance (Thayer et al., 2010, Schaich et al., 2020). Interestingly, the literature has reported that individual indices of HRV seem to relate differently to various CVD and neurocognitive performance measures (Forte et al., 2019).

3.2.1 White-Collar Heart Rate Variability during the Neurocognitive Tasks

Spatial Working Memory

In the white-collar group, it was found that the high frequency (HF) parameter decreased and the ratio of low frequency (LF) to HF increased during the SWM task. High Frequency HRV represents the parasympathetic activity (Malik et al., 1996, Laborde et al., 2017). Both the polyvagal theory (Porges, 2007) and the neurovisceral integration model (Thayer et al., 2009) indicate the vagal influence on the heart whereby, higher vagal tone shows better executive function (Forte et al., 2019). Similarly, further studies have shown parasympathetic activity declines under loads of cognitive stress (Byrd et al., 2014). Byrd et al. (2014) analysed 25 children (16 males, 9 females, mean age = 8.6

years) and 34 adults (19 males, 15 females, mean age = 22 years) during the Stroop (Stroop, 1935a), the Tower of London (Shallice, 1982), and the N-Back (Kirchner, 1958) and showed that increasing the difficulty of the tasks, and therefore increasing executive load, resulted in decreases in HRV and performance, particularly in the working memory (WM) tasks. The present study also found a dominance of sympathetic activity during the SWM task for the white-collar group. Coupled with the decrease in parasympathetic activity, the sympathetic activation is likely a result of acute mental stress from exposure to a novel task or activity that the white-collar workers are not routinely used to (Holly et al., 1997), particularly activities which require manoeuvring through the 3D space around them (e.g., the SWM task). Contrastingly, an increase in RMSSD was observed, which the literature has shown to be correlated with HF HRV (Kleiger et al., 2005). However, the effect of respiration rate on HF HRV is still uncertain and may explain the variation observed in the present study (Schipke et al., 1999, Penttilä et al., 2001).

Attention Switching

During the AST, white-collar workers showed a reduction in LF HRV. Previously thought to be indicative of sympathetic activity, the interpretation of LF has been contended as some studies suggest other factors influence the LF HRV (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The LF power may be produced by both branches of the ANS, baroreceptors, and respiratory sinus arrhythmia (RSA) (Akselrod et al., 1981, Berntson et al., 2007, Reyes del Paso et al., 2013). The literature has shown lower LF HRV to be linked to worse performance in regards to memory (Backs and Seljos, 1994, Frewen et al., 2013), which is supported by a recent review suggesting lower sympathetic and parasympathetic activity may predispose to worse cognitive performance (Forte et al., 2019).

Rapid Visual Processing

Total power (TP) HRV and SDNN parameters fell during the RVP task, which is a measure of sustained attention task (Waller et al., 2016). Both of these HRV parameters have been shown to be highly correlated (Umetani et al., 1998) and are markers of overall HRV, where TP is the spectral derivative while SDNN is the time-domain measure. An earlier study by Tsuji et al. (1996) indicated that both TP and SDNN were significantly associated with increased risk for cardiac events in a healthy population during a 3-year follow-up (n = 2501, mean age = 53.7 ± 5.6 years, 44% male). Even though the authors drew conclusions based on a short recording of HRV (2 hours), it was one of the first prospective studies in a community-based population (Tsuji et al., 1996). A more recent community-based study of n = 9744 healthy people (aged between 45-64 years, 42% male) showed similar findings, where authors recorded 2856 CVD events and found that individuals with decreased HRV may have an increased risk of experiencing a cardiac event (Kubota et al., 2017).

Spatial Span

During the SSP task, the white-collar group showed a significant decrease in HF HRV, and overall TP, as well as an increase in LF/HF, signifying increased sympathetic dominance. The SSP task is an assessment of working memory capacity, which measures how many 'items' can be held in mind for the current task (Cambridge Cognition, 2021). This is a skill that white-collar workers must utilise daily when juggling administrative and organisational tasks in addition to other work in their respective fields. Therefore, it was expected that sympathetic dominance would diminish during such tasks, but this was not the case in the current study. Though there seems to be dominance of sympathetic activity, the LF/HF ratio is controversial (Billman, 2013, Shaffer and Ginsberg, 2017) as it appears that different processes that influence this index depend on the task and the time frame of the recording, for example, 24 hour HRV data compared to 5 minute HRV data (Shaffer et al., 2014). The longer-term HRV data (24 hour) is said to be more accurate in illustrating the balance of the LF/HF ratio as the changes during the day from emotional and physical stress show sympathetic dominance (Shaffer et al., 2014). The SSP task creates neurocognitive stress by increasing workload on executive functions. Despite the shorter HRV data in the present study (10 minutes), the findings support the literature, indicating that this increased stress reflects a higher LF/HF ratio and therefore, increased sympathetic dominance (Shaffer et al., 2014).

3.2.2 Associations between Heart Rate Variability and Neurocognitive Performance in White-Collar Workers

During the AST, the ratio of sympathetic to parasympathetic activity (LF/HF) was inversely associated with the number of errors made (i.e., more errors were made when the parasympathetic activity was dominating). This indicates higher parasympathetic activity is related to worse performance in the AST. This is in contrast to the work of Colzato et al. (2018) who studied 90 undergraduate students (33% male, average age = 22.1 ± 2.5 years) and found that higher vagally mediated HRV (vmHRV) (parasympathetic drive) predicted better task-switching through greater cognitive flexibility. In accordance with the neurovisceral integration model by Thayer et al. (2009), higher vmHRV reflects better functioning of the inhibitory circuits in the prefrontal cortex (PFC) which in turn improves mental flexibility. Given the parasympathetic association with better performance and the controversy around LF/HF ratio, this finding may further support previous literature indicating that the LF portion of the LF/HF ratio has parasympathetic influences (Shaffer et al., 2014). Conversely, TP HRV showed an inverse association with reaction time while higher RMSSD was correlated with less errors made. As both TP HRV and RMSSD HRV are known to be strong markers of parasympathetic activity, particularly RMSSD, this finding is in support of the aforementioned study by Colzato et al. (2018) and the wider literature, which stipulates that higher parasympathetic drive is associated with better neurocognitive performance.

The literature suggests that greater variability in performance reflects inefficient prefrontal cortex (PFC) activity, and thus, poor cognitive processing (MacDonald et al., 2006, Hultsch et al., 2008). Bellgrove et al. (2004) investigated the changes in HRV data during an inhibition task within 42 participants (29 females, average age = 31 years). These authors discovered that greater variability was associated with an increase in frontal lobe activation, which was attributed to greater demand for executive control to maintain task performance (i.e., participants with HRV data that changed more actually show less efficient frontal cortex response to executively demanding tasks). This notion was further supported by Byrd et al. (2014) who examined phasic HF HRV in response to executive function tasks in 34 adults (19 males, average age = 22 years) and 25 children

(16 males, average age = 8.6 years). They performed the Stroop task (inhibition) (Stroop, 1935a), Tower of London (planning) (Shallice, 1982), and the N-Back (working memory) (Kirchner, 1958). These investigators found that HRV responsivity in adults increased with increased executive load in the WM task but not in the planning task (Byrd et al., 2014). This may suggest that the different HRV parameters may vary in different ways depending on the task being performed. Ultimately, it was noted that increases in executive load results in decreases in vagal tone, the ability of the heart to adapt in certain situations (adaptability of HRV), and in neurocognitive performance (Backs and Seljos, 1994, Hansen et al., 2003, Byrd et al., 2014, Muthukrishnan et al., 2015).

3.3 Conclusions: HRV and Neurocognitive Performance in White-Collar Workers

Overall, the white-collar worker group showed a number of significant changes in HRV during neurocognitive performance tasks. Of note, reductions in parasympathetic activity were identified during memory and attention tasks. This is well supported by the literature (Holly et al., 1997, Byrd et al., 2014), indicating the highly adaptive nature of the cardiovascular system is dampened in response to mental load or stress. Moreover, previous studies have found that reductions in HRV have been linked to increased mental stress as well worse performance during these tasks (Duschek et al., 2009, Luft et al., 2009). This same reduction in HRV has also been previously linked to increased likelihood of CVD (Colhoun et al., 2001, Thayer et al., 2010).

These findings not only provide further evidence of the polyvagal theory, originally stipulated by Porges (2007), but also the neurovisceral integration model introduced by Thayer et al. (2009). However, much of the research conducted provides HRV information obtained during baseline HRV, or reductions in HRV as we progress through life, that is, effects of ageing. The present study reported in this thesis provides additional insight into the underlying interactions between the brain and the cardiovascular system. Continuing from this study further research into how HRV is influenced by neurocognitive tasks may provide a better understanding into the additional fundamental processes which predispose us to CVD.

The present study also found multiple links between HRV and neurocognitive performance in the white-collar workers. As vagal tone increased, associations (both positive and negative) were observed with errors recorded on the tasks and the reduced reaction times. This supports the notion that higher vagally-mediated HRV, or parasympathetic activity, is related to better neurocognitive performance. However, given some individual indices of HRV (LF/HF, TP, and RMSSD) were found to have correlations during some tasks (AST and SSP) and not others suggests that the classic assumptions, that higher parasympathetic activity reflects better neurocognitive performance and high sympathetic activity reflects worse performance, are challenged. That is, the relationships between higher resting levels of cardiac vagal tone and improved mental ability may not necessarily hold universally (Duschek et al., 2009). The findings of the current study indicate that the indices of cardiac activity may behave differently according to the specific task being performed. As such, the mechanisms that underlie working memory and attention are still not fully understood and therefore, may have other influences which warrant further research into the links between cardiac autonomic indices and neurocognitive performance.

Chapter 4 HRV and Neurocognitive Performance (Blue-Collar Workers)

4.1 Results: Blue-Collar Workers

This chapter delineates the descriptive statistics of the blue-collar worker group and the results of neurocognitive performance and HRV for this group (n = 53). As discussed previously in Methods Section 2.7.1, the sample power for this group is adequate for the analyses that were performed and are presented herein. A total of 53 blue-collar volunteers with no chronic illness, aged between 19 and 57 (36.85 ± 11.3) years, were recruited for the present study.

Figure 4.1 displays the breakdown of the blue-collar workforce in this sample. This sample included full-time employees who are drivers (taxi and Uber) (n = 23), security guards (n = 14), plumbers (n = 6), electricians (n = 3), and construction workers (n = 7).

Figure 4.1 Blue-Collar Worker Sample Distribution by Position (n = 53)

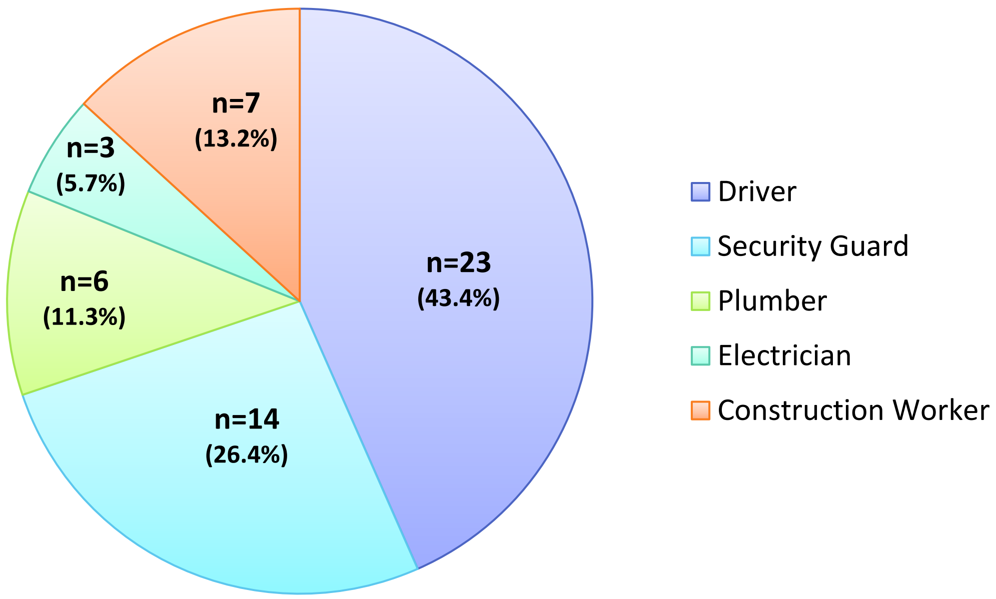


Figure 4.1 displays the breakdown of the blue-collar worker sample (n = 53) in this study. These included 23 drivers, 14 security guards, 6 plumbers, 3 electricians, and 7 construction workers.

Key; n = Sample size

4.1.1 Demographics

Demographic data (mean ± SD) for the blue-collar worker sample population are provided in Table 4.1. The participants were aged between 19-57 years with a mean age of 36.85 ± 11.28 years. This blue-collar group was comprised of 11 females (19%) and 42 males (81%) and had a mean BMI of 22.70 ± 2, the normal range for BMI is indicated between 19-25 (Garrouste-Orgeas et al., 2004). In this group, the average time spent on formal education was 3.4 ± 1.19 years, and they scored an average of 6.9 ± 2 on the General Health Questionnaire (GHQ) (Goldberg, 1972). The GHQ has a maximum score of 30 with a threshold of 12. Any scores above this threshold indicates increasingly poor psychological wellbeing (Goldberg and Williams, 2006).

Table 4.1 Mean Demographics for the Blue-collar Worker Population (n = 53)

Demographic	**Mean ± SD**
Years of Age	36.85 ± 11.28
Male (n; %) **Female (n; %)**	n = 42 (81%) n = 11 (19%)
BMI	22.7 ± 2
Years of Education	3.4 ± 1.2
GHQ Score	6.9 ± 2

Table 4.1 exhibits the mean demographic scores for the blue-collar worker population (n = 53). This sample is within the normal BMI reference range of 19-23 (Garrouste-Orgeas et al., 2004). The threshold for the GHQ (Goldberg, 1972) is 12 with a maximum score of 30 and with higher scores indicating worse psychological health (Goldberg and Williams, 2006).

Key: BMI = Body mass index; GHQ = General health questionnaire (Goldberg, 1972); n = Sample size; SD = standard deviation; % = Percentage

4.1.2 Neurocognitive Performance Measures

Outcome measures (mean ± SD) from the neurocognitive performance tasks, Spatial Working Memory (SWM), Attention Switch task (AST), Rapid Visual Processing (RVP), and Spatial Span (SSP) task are shown in Table 4.2.

It is noted that some large variances exist in the data sets presented. The tests performed in the present study have shown correlations with traditional neurocognitive tests (e.g., the Wechsler adult intelligence scale (Wechsler, 1997)), however, the correlations show less consistency when controlling for age and education (Smith et al., 2013). It is also important to note that neurocognitive tests that are highly validated may not necessarily correlate (Golden et al., 1998, Miller et al., 2009). Therefore, the underlying process being assessed may be attributing to the observed variation, as test-retest variability in neurocognitive performance measures is known to be quite common (Luciana, 2003).

Spatial Working memory

In the SWM task, strategy was determined by the number of times the participant started the search from a new position. As this test is performed by processes of elimination, a higher number indicates less use of strategy. This follows as the participant is using chance to find the token. The blue-collar workers initiated their search from a new position 6.26 ± 2.25 times.

The additional measures from this test include the errors made, particularly errors made in the 4-box trial (0.15 ± 0.36), 6-box trial (1.60 ± 1.36), 8-box trial (2.13 ± 1.91), and total errors (3.89 ± 2.27) over all trials.

Attention Switching Task

The AST showed the congruent (2.62 ± 2.18) and incongruent errors (9.40 ± 3.62), errors made on the “arrow” cue (4.91 ± 2.41) and “side” cue (3.19 ± 2.16), and the total correct responses (139.43 ± 9.80). Additionally, the AST measured reaction time for different aspects of the test including the “direction” cue (688.41 ± 236.47), “side” cue (607.81 ± 182.27), all incongruent cues (734.33 ± 257.91), and all correct trials (596.78 ± 205.62).

Rapid Visual Processing

The RVP task identified the ability to detect the signals (0.85 ± 0.08), reaction time (448.07 ± 55.80), and the number of sequences that were detected (37.06 ± 11.76) and missed (37.06 ± 11.76).

Spatial Span

Finally, the SSP task measured the longest sequence remembered (8.02 ± 1.10), and the errors made that were not next in the sequence (9.74 ± 6.55) and those that are not in the sequence at all (1.25 ± 1.12).

Table 4.2 Mean Neurocognitive Performance Measures for the Blue-collar Workers (n = 53)

Neurocognitive Task	Measure	Mean ± SD
Spatial Working Memory	Strategy	6.26 ± 2.25
	Total Errors	3.89 ± 2.27
	Errors 4	0.15 ± 0.36
	Errors 6	1.60 ± 1.36
	Errors 8	2.13 ± 1.91
Attention Switching Task	Congruent Errors	2.62 ± 2.18
	Arrow Errors	4.91 ± 2.41
	Incongruent Errors	9.40 ± 3.62
	Latency (direction cue) (ms)	688.41 ± 236.47
	Latency (incongruent cue) (ms)	734.33 ± 257.91
	Latency (all correct trials) (ms)	596.78 ± 205.62
	Latency (side cue) (ms)	607.81 ± 182.27
	Side Errors	3.19 ± 2.16
	Total Correct	139.43 ± 9.80
	Total Incorrect	11.60 ± 5.64
Rapid Visual Processing	Signal Detection	0.85 ± 0.08
	Reaction Time (correct) (ms)	448.07 ± 55.80
	Total Sequences Detected	37.06 ± 11.76
	Total Sequences Missed	16.94 ± 11.76
Spatial Span	Longest Sequence	8.02 ± 1.10
	Errors (not next in sequence)	9.74 ± 6.55
	Total Errors (not in sequence at all)	1.25 ± 1.12

Table 4.2 shows the mean ± SD for the main measures obtained in the neurocognitive tasks (SWM, AST, RVP, SSP) for the blue-collar worker group (n = 53).

Key: ms = Milliseconds; n = Sample size; SD = Standard deviation

4.1.3 Heart Rate Variability Parameters

The differences (mean ± SD) for baseline heart rate variability parameters (frequency and time domain) in the blue-collar sample are displayed in Table 4.3. Logarithmic transformations were applied to reduce the effect of skewed HRV data (Tarvainen et al., 2009). The logarithmically-transformed HRV data was subsequently used for further statistical analysis.

The HRV results displayed in Table 4.3 were obtained at rest and will henceforth be referred to as baseline data. HRV data obtained during all active tasks (the neurocognitive tasks) (Table 4.4, 4.5, 4.6, and 4.7) was be compared to the baseline HRV data (Table 4.3). That is, data will be reported as active minus baseline (denoted: cardiac reactivity) in each case. Additionally, all the significant findings are presented as a summary table at the end of Section 4.1.4 (Table 4.8).

Table 4.3 Mean Baseline HRV Parameters for the Blue-collar Workers (n = 53)

HRV State		HRV Parameter	Mean ± SD
Baseline	Frequency Domains	Low Frequency (ms^2)	608.05 ± 236.88
		High Frequency (ms^2)	528.51 ± 1046.30
		LF/HF	5.19 ± 2.57
		Total Power (ms^2)	1221.30 ± 1059.04
		Log Low Frequency (ms^2)	6.33 ± 0.411
		Log High Frequency (ms^2)	5.05 ± 1.30
		Log LF/HF	1.28 ± 1.24
		Log Total Power (ms^2)	6.85 ± 0.64
	Time Domains	Mean RR (ms)	820.80 ± 44.63
		SDNN (ms)	34.02 ± 12.38
		RMSSD (ms)	26.39 ± 19.59
		pNN50 (%)	6.57 ± 12.96
		Log RMSSD (ms)	6.71 ± 0.05
		Log SDNN (ms)	3.47 ± 0.31

Table 4.3 shows the baseline values of HRV parameters for the blue-collar worker group (n = 53).

Key: HRV = Heart rate variability; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = percentage of NN (beat to beat) intervals greater than 50 milliseconds; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); % = Percentage

The HRV measures (mean ± SD) and cardiac reactivity data for HRV frequency and time domain measures are reported for all neurocognitive performance tasks: Spatial Working Memory (SWM) (Table 4.4), Attention Switching task (AST) (Table 4.5), Rapid Visual Processing (RVP) (Table 4.6), and the Spatial Span (SSP) (Table 4.7).

Dependent sample t-tests were performed to determine any significant changes between baseline and the active phases. These are highlighted in red throughout the tables below and reported collectively as a summary in Table 4.8.

HRV parameters (mean ± SD) during the SWM task (Table 4.4) were compared to baseline data in Table 4.3. Log LF was significantly decreased between baseline (6.33 ± 0.41 ms^2) and active (6.02 ± 0.48 ms^2), and log TP was also significantly decreased from baseline (6.80 ± 0.55 ms^2) to active (6.48 ± 0.37 ms^2).

Table 4.4 Mean HRV during the Spatial Working Memory Task for the Blue-collar Workers (n = 53)

HRV State		HRV Parameter	Mean ± SD	Cardiac Reactivity (Mean ± SD)	t	df	p
SWM	Frequency Domains	LF (ms^2)	454.39 ± 205.13	-153.66 ± 261.38	4.28	52	0.00
		HF (ms^2)	152.07 ± 122.31	-376.44 ± 995.28	2.75	52	0.008
		LF/HF	4.50 ± 2.94	-0.69 ± 2.23	2.25	52	0.029
		TP (ms^2)	1070.4 ± 224.89	-150.9 ± 1056.88	3.63	52	0.001
		Log LF (ms^2)	6.02 ± 0.48*	-0.32 ± 0.47	4.79	51	<0.001
		Log HF (ms^2)	4.79 ± 0.64	-0.26 ± 0.97	1.93	51	0.06
		Log LF/HF	1.23 ± 0.83	-0.06 ± 0.97	0.41	51	0.68
		Log TP (ms^2)	6.48 ± 0.37*	-0.37 ± 0.60	4.41	51	<0.001
	Time Domains	Mean RR (ms)	831.72 ± 68.49	10.69 ± 47.64	-1.44	53	0.16
		SDNN (ms)	34.79 ± 12.55	0.75 ± 14.84	-0.22	53	0.56
		RMSSD (ms)	29.76 ± 19.08	3.37 ± 20.97	-0.99	53	0.33
		pNN50 (%)	6.82 ± 4.45	0.25 ± 11.64	2.6	53	0.012
		Log RMSSD (ms)	6.72 ± 0.08	0.01 ± 0.05	-1.32	51	0.19
		Log SDNN (ms)	3.50 ± 0.31	0.03 ± 0.05	-0.6	51	0.55

Table 4.4 indicates the mean HRV parameters during the Spatial Working Memory task for the blue-collar worker group (n = 53). Red asterisks signify significant differences ($p < 0.05$) between baseline and active phases.

Key: df = Degrees of freedom; HF = High Frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = Percentage of NN (beat to beat) intervals greater than 50 milliseconds; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); SWM = Spatial working memory; TP = Total power; % = Percentage; * = p = Level of statistical significance (< 0.05)

HRV parameters (mean ± SD) during the AST (Table 4.5) were compared to baseline HRV data in Table 4.3. Log RMSSD was shown to be significantly reduced from the baseline (6.71 ± 0.05 ms) to the active (6.69 ± 0.08 ms) phase.

Table 4.5 Mean HRV during the Attention Switching Task for the Blue-collar Workers (n = 53)

HRV State		HRV Parameter	Mean ± SD	Cardiac Reactivity (Mean ± SD)	t	df	p
AST	Frequency Domains	LF (ms^2)	573.43 ±168.39	-34.62 ± 253.92	0.99	52	0.33
		HF (ms^2)	144.34 ± 91.58	-384.17 ± 1038.3	2.69	52	0.01
		LF/HF	5.04 ± 2.02	-0.15 ± 2.32	0.48	52	0.64
		TP (ms^2)	847.4 ±226.16	-373.90 ± 1136.5	2.4	52	0.02
		Log LF (ms^2)	6.31 ± 0.34	-0.02 ± 0.40	0.43	51	0.68
		Log HF (ms^2)	4.78 ± 0.59	-0.27 ± 1.30	1.5	51	0.14
		Log LF/HF	1.53 ± 0.50	0.25 ± 1.06	-1.68	51	0.1
		Log TP (ms^2)	6.70 ± 0.31	-0.15 ± 0.72	1.49	51	0.14
	Time Domains	Mean RR (ms)	809.19 ± 70.83	-11.27 ± 33.65	0.25	53	0.02
		SDNN (ms)	32.98 ± 7.83	-1.04 ± 13.0	0.6	53	0.56
		RMSSD (ms)	25.24 ± 12.19	-1.14 ± 18.69	0.46	53	0.65
		pNN50 (%)	2.35 ± 1.81	-4.22 ± 11.53	2.74	53	0.01
		Log RMSSD (ms)	6.69 ± 0.08*	-0.02 ± 0.04	2.61	51	0.01
		Log SDNN (ms)	3.47 ± 0.24	-0.02 ± 0.04	0.08	51	0.94

Table 4.5 shows the mean HRV during the Attention Switching task for the blue-collar worker group (n = 53). The red highlighted text with an asterisk signifies significant differences ($p < 0.05$) from baseline. These values are reported in Table 4.7. Cardiac reactivity refers to active minus baseline HRV data.

Key: AST = Attention switching task; df = Degrees of freedom; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = Percentage of NN (beat to beat) intervals greater than 50 milliseconds; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); t = T statistic; TP = Total power; % = Percentage; * = p = Level of statistical significance (< 0.05)

HRV parameters (mean ± SD) during the RVP task (Table 4.6) were compared to baseline HRV data in Table 4.3. Log RMSSD showed a significant increase from the baseline (6.71 ± 0.05 ms) to active the (6.72 ± 0.08 ms) phase.

Table 4.6 Mean HRV during the Rapid Visual Processing Task for the Blue-collar Workers (n = 53)

HRV State		HRV Parameter	Mean ± SD	Cardiac Reactivity (Mean ± SD)	t	df	p
RVP	Frequency Domains	LF (ms^2)	661.21 ± 191.68	53.16 ± 294.55	-1.31	52	0.2
		HF (ms^2)	212.98 ± 87.88	-315.53 ± 992.21	2.32	52	0.03
		LF/HF	3.58 ± 1.52	-1.62 ± 2.02	5.83	52	0.00
		TP (ms^2)	1012.84 ± 243.09	-208.46 ± 1065.96	1.14	52	0.16
		Log LF (ms^2)	6.44 ± 0.33	0.11 ± 0.46	-1.74	51	0.09
		Log HF (ms^2)	5.27 ± 5.27	0.22 ± 1.11	-1.42	51	0.16
		Log LF/HF	1.17 ± 0.50	-0.11 ± 1.07	0.74	51	0.47
		Log TP (ms^2)	6.89 ± 0.27	0.04 ± 0.66	-0.39	51	0.7
	Time Domains	Mean RR (ms)	832.96 ± 66.51	12.06 ± 33.54	-2.69	53	0.01
		SDNN (ms)	34.09 ± 3.89	0.07 ± 11.26	-0.05	53	0.96
		RMSSD (ms)	27.05 ± 6.82	0.66 ± 16.41	-0.30	53	0.77
		pNN50 (%)	4.19 ± 6.14	-2.38 ± 9.07	1.97	53	0.05
		Log RMSSD (ms)	6.72 ± 0.08*	0.01 ± 0.04	-2.6	51	0.01
		Log SDNN (ms)	3.53 ± 0.12	0.01 ± 0.04	-1.43	51	0.16

Table 4.6 displays the mean HRV during the Rapid Visual Processing task for the blue-collar worker group (n = 53). The red highlighted text with an asterisk signifies significant differences ($p < 0.05$) from baseline.

Key: df = Degrees of freedom; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = Percentage of NN (beat to beat) intervals greater than 50 milliseconds; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); TP = Total power; % = Percentage; * = p = Level of statistical significance (< 0.05)

HRV parameters (mean ± SD) during the SSP (Table 4.7) were compared to the baseline levels. There were no significant differences observed in the active data (Table 4.7) as compared to baseline data (Table 4.3).

Table 4.7 Mean HRV during the Spatial Span Task for the Blue-collar Workers (n = 53)

HRV State		HRV Parameter	Mean ± SD	Cardiac Reactivity (Mean ± SD)	df	t	p
SSP	Frequency Domains	LF (ms^2)	740.57 ± 305.52	132.52 ± 471.00	-2.05	52	0.05
		HF (ms^2)	205.99 ± 176.54	-322.52 ± 1091.09	2.15	52	0.04
		LF/HF	4.47 ± 1.48	-0.72 ± 3.05	5.82	52	0.00
		TP (ms^2)	1044.38 ± 441.00	-176.92 ± 1256.83	1.42	52	0.16
		Log LF (ms^2)	6.51 ± 0.54	0.17 ± 0.82	-1.53	51	0.13
		Log HF (ms^2)	5.07 ± 0.67	0.02 ± 1.60	-0.11	51	0.92
		Log LF/HF	1.44 ± 0.37	0.16 ± 1.33	-0.85	51	0.4
		Log TP (ms^2)	6.88 ± 0.36	0.03 ± 0.85	-0.28	51	0.78
	Time Domains	Mean RR (ms)	801.86 ± 163.10	-18.94 ± 171.41	0.83	53	0.41
		SDNN (ms)	63.97 ± 155.53	29.95 ± 155.86	-1.44	53	0.16
		RMSSD (ms)	28.08 ± 20.20	1.69 ± 29.84	-0.42	53	0.67
		pNN50 (%)	5.77 ± 7.39	-0.80 ± 16.07	0.37	53	0.71
		Log RMSSD (ms)	6.66 ± 0.45	-0.05 ± 0.45	0.86	51	0.4
		Log SDNN (ms)	3.58 ± 0.48	0.12 ± 0.59	-1.42	51	0.16

Table 4.7 shows the mean HRV during the Spatial Span task for the blue-collar worker group (n = 53).

Key: df = Degrees of freedom; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Ratio of low to high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; pNN50 = Percentage of NN (beat to beat) intervals greater than 50 milliseconds; p = Level of statistical significance; RMSSD = Root mean square of successive differences; RR = Time in milliseconds from one R peak to the next R peak in an electrocardiogram; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span task; t = T statistic; TP = Total power; % = Percentage

4.1.4 Summary of Heart Rate Variability Findings

For the blue-collar worker group, dependent sample t-tests were performed to determine if there were any significant changes between the baseline and active (neurocognitive performance task) HRV phases. A summary of all the significant findings is presented in Table 4.8.

During the SWM task a significant decrease in log LF was found between the baseline (6.33 ± 0.411 ms^2) and active (6.02 ± 0.48 ms^2) phase, as well as in log TP from baseline (6.80 ± 0.55 ms^2) to active (6.48 ± 0.37 ms^2).

Throughout the AST a significant reduction in log RMSSD was identified in the active (6.69 ± 0.08 ms) phase, compared to the baseline (6.71 ± 0.05 ms).

Interestingly, during the RVP task, log RMSSD increased significantly from baseline (6.71 ± 0.05 ms) to active (6.72 ± 0.08 ms).

These findings are displayed in Table 4.8.

Table 4.8 Dependent Sample t-test between Baseline and Active HRV in the Blue-collar Workers (n = 53)

Task	Variable	t	df	p	Baseline mean ± SD	Active mean ± SD	Mean difference (active-baseline)
SWM	Log LF (ms^2)	4.79	51	<0.001	6.33 ± 0.41	6.02 ± 0.48	-0.32
	Log TP (ms^2)	4.41	51	<0.001	6.80 ± 0.55	6.48 ± 0.37	-0.32
AST	Log RMSSD (ms)	2.61	51	0.01	6.71 ± 0.05	6.69 ± 0.08	-0.017
RVP	Log RMSSD (ms)	-2.60	51	0.01	6.71 ± 0.05	6.72 ± 0.08	0.013

Table 4.8 displays the significant findings from dependent sample t-tests between baseline and active (neurocognitive task) HRV states for the blue-collar worker group (n = 53).

Key: AST = Attention switching task; df = Degrees of freedom; LF = Low frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; p = Level of statistical significance ($p < 0.05$); RMSSD = Root mean square of successive differences; RVP = Rapid visual processing; SD = Standard deviation; SWM = Spatial working memory; t = T statistic; TP = Total power

4.1.5 Correlations between Neurocognitive Performance and HRV

The data has been corrected for confounders and partial Pearson's correlations were performed to determine correlations between the HRV parameters and the neurocognitive performance measures for the blue-collar group which are displayed in Table 4.9 below. Correlation graphs for the blue-collar worker group are displayed in Figure 4.2 and Figure 4.3.

Baseline

Partial Pearson's correlation identified that baseline log RMSSD was positively associated with the ability to detect signals (r = 0.28, p = 0.04) when controlling for age. Baseline LF/HF was negatively associated with the reaction time on correct trials (r = -0.276, p = 0.048) while controlling for BMI.

Rapid Visual Processing

During the RVP task, log LF was negatively correlated with the ability to detect signals (r = -0.282, p = 0.04) while controlling for age.

Table 4.9 Partial Pearson's Correlation between HRV and Neurocognitive Performance in the Blue-collar Workers (n = 53)

Task	Covariate	Dependent Variable	Independent Variable	r	p
Baseline	Age (years)	Log RMSSD	Signal Detection	0.28	0.04
	BMI	Log LF/HF	Reaction Time (correct)	-0.276	0.048
RVP	Age (years)	Log LF	Signal Detection	-0.282	0.04

Table 4.9 displays the significant results from a partial Pearson's correlation between HRV and the cognitive performance scores in the blue-collar group (n = 53).

Key: BMI = Body mass index; HRV = Heart rate variability; LF = Low frequency; LF/HF = Low frequency divided by high frequency; p = Level of statistical significance (p < 0.05); r = Correlation coefficient; RMSSD = Root mean squared of successive differences; RVP = Rapid visual processing

Correlation graphs for the blue-collar group are displayed in Figure 4.2 and 4.3. Figure 4.2 shows the positive relationship found to exist between log RMSSD and the ability to detect signals (r = 0.28, p = 0.04) during the RVP task. This demonstrates that as the ability to detect sequences increases, log RMSSD (parasympathetic activity) increases.

Figure 4.3 shows the inverse relationship detected between log LF and signal detection (r = -0.282, p = 0.04) during the RVP task. This indicates that as signal detection increases, log LF (sympathetic activity) decreases.

Figure 4.2 Correlation Graphs between Log RMSSD and Signal Detection for Blue-Collar Workers (n = 53).

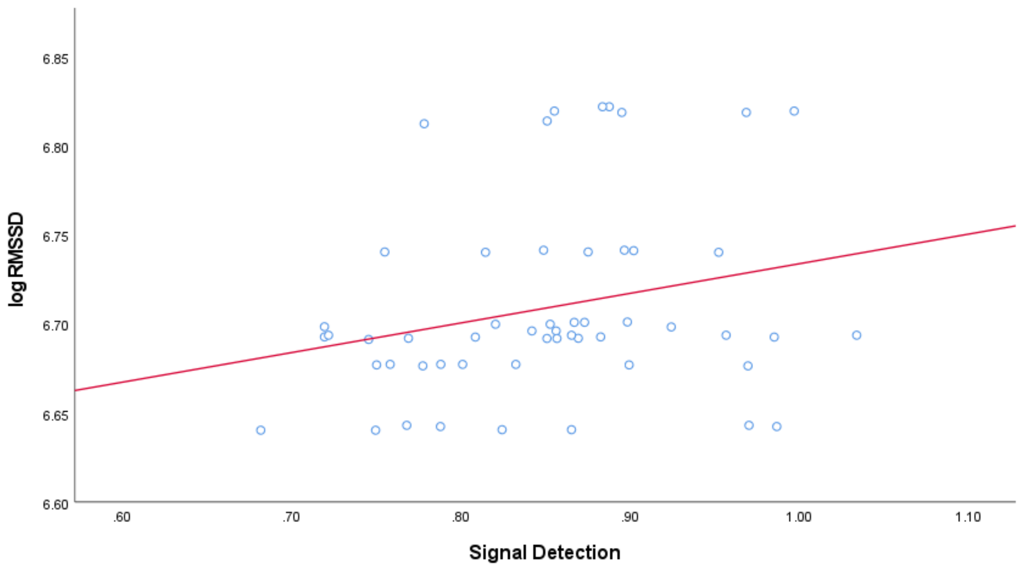


Figure 4.2 displays a positive relationship between log RMSSD and signal detection (r = 0.28, p = 0.04) for the blue-collar workers (n = 53).

Key: n = Sample size; p = Level of statistical significance ($p < 0.05$); r = Correlation coefficient; RMSSD = Root mean squared of successive differences

Figure 4.3 Correlation Graph between Log LF and Signal Detection for the Blue-Collar Workers (n = 53)

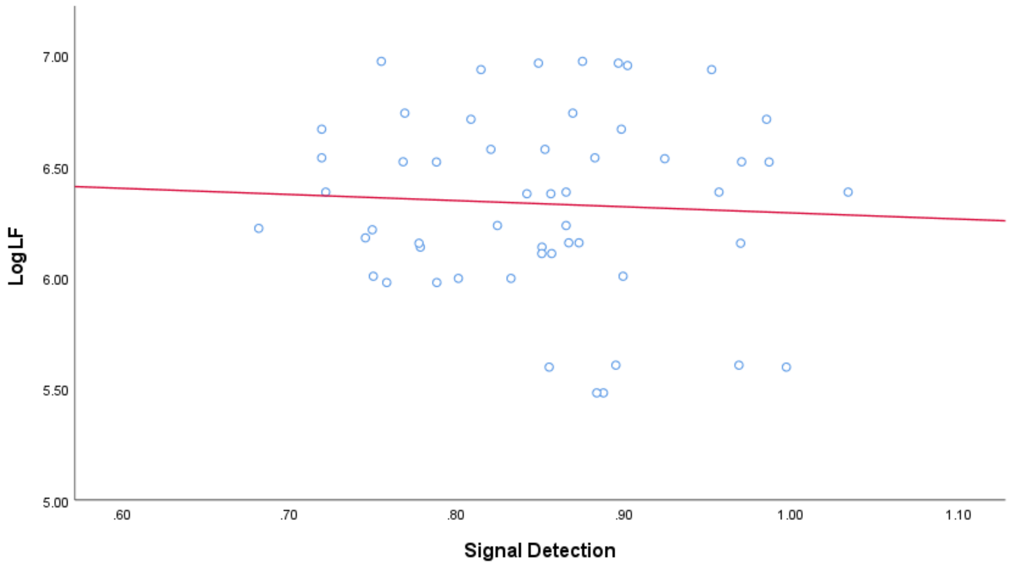


Figure 4.3 displays an inverse relationship between log LF and signal detection during the RVP task (r = -0.282, p = 0.04) for the blue-collar workers (n = 53).

Key: LF = Low frequency; n = Sample size; p = Level of statistical significance ($p < 0.05$); r = Correlation coefficient; RVP = Rapid visual processing

4.2 Discussion: Blue-Collar Workers

The current chapter has presented and will now discuss the HRV and the neurocognitive performance findings in the blue-collar worker group (n = 53). The aims were to investigate differences in HRV parameters between the baseline and active (neurocognitive tasks) phases (Chapter 1.7, Aim 1), and to determine associations between HRV parameters and neurocognitive performance measures (Chapter 1.7, Aim 2). It was hypothesised that differences in HRV parameters would be observed between the baseline and active task phases, and that associations would also be observed between HRV parameters and neurocognitive function measures (Chapter 1.8, Hypotheses 1 and 2, respectively). The hypotheses were accepted, as shown by the results presented in this chapter.

The results observed were identified during the neurocognitive tasks undertaken by the participants (i.e., spatial span (SSP), attention switching task (AST), rapid visual processing (RVP) and spatial working memory (SWM)) (Cambridge Cognition, 2021).Previous studies regarding cardiovascular disease (CVD) and workers identified associations between socio-economic status, shift work, and CVD (Smith et al., 1992, Fukuda et al., 2005). A possible explanation may come from the differences in educational background and lifestyle surrounding various socio-economic groups. This is further discussed in Chapter 5 (Section 5.2) where the HRV parameters and neurocognitive performance measures of the white-collar workers are compared against those of the blue-collar workers. Moreover, according to a brief in the Journal of the American Medical Association (JAMA), blue-collar workers are 40% more likely to report a history of coronary heart disease (CHD) or stroke as compared to white-collar workers of the same age group (Voelker, 2014).

4.2.1 Blue-Collar Heart Rate Variability during the Neurocognitive Tasks

Spatial Working Memory

In the blue-collar worker group, decreases in low frequency (LF) HRV and total power (TP) HRV during the SWM task were observed. This suggests that the increased mental load reduces the overall variability of the heart. Supported by the findings of Ha et al. (2001), it was identified that both sympathetic and parasympathetic activity showed a decreasing trend as the shift continued. The authors examined the effects of shift work on the HRV of 134 male workers (average age = 29 years, between 25-44 years) and further showed that shift work imposes negative health effects on the cardiovascular system. Additionally, Lee et al. (2015) investigated the effect of circadian rhythm disruption on HRV in male, blue-collar automobile manufacturing workers (n = 162, average age = 32.1 ± 5.8 years). The authors corroborated the findings, which reflects reduced LF HRV in shift workers and further found even lower LF HRV during the night shifts (Lee et al., 2015). Despite not comparing to regular/fixed-hour workers this study does provide some basis for the effect of blue-collar jobs on HRV and its disruption of HRV (Lee et al., 2015). However, a study by van Amelsvoort et al. (2001) investigated the increased risk of CVD and its relationship to unfavourable changes of autonomic cardiac control, namely ventricular premature complexes and HRV, in a blue-collared worker sample in the manufacturing industry and waste incinerator plants. These authors recorded HRV over a period of 1 year and examined 32 daytime (average age = 29.3 ± 5.3 years, female = 9%) and 75 shift work workers(average age = 30.4 ± 6.7 years, female = 11%) (van Amelsvoort et al., 2001). Despite finding an increased prevalence of ventricular premature complexes, no significant changes in HRV were reported (van Amelsvoort et al., 2001).

Attention Switching

During the AST, the blue-collar worker group showed a significant reduction in RMSSD. Given this is an index of parasympathetic activity, this suggests the increased difficulty and mental load that blue-collar workers experience during sustained attentional tasks, particularly when these tasks are performed on a computer and not within the surrounding space to which they are accustomed. Early on, Porges and Raskin (1969) found that sustained attention caused significant reductions in HRV. Moreover, the shift work nature of the blue-collar worker professions seems to have detrimental effects on health and HRV. Hulsegge et al. (2018) examined 665 blue-collar workers (average age = 45.5 ± 9.7 years, male = 56%) and found a significantly lower SDNN and RMSSD. This may reflect reduced parasympathetic activity, and authors interpreted this as a weakened ability of the autonomic nervous system to adapt to internal and external challenges (Hulsegge et al., 2018).

Rapid Visual Processing

Finally, the blue-collar worker group showed a small, albeit significant, increase in RMSSD during the RVP task which may indicate increased variability and vagal tone during tasks that require pattern recognition. Whether it is a driver planning a route, a plumber orienting in 3D space, or a construction worker laying bricks, most blue-collared professions require some degree of pattern recognition, and this may reflect their adaption to increased vagal control. However, the blue-collared professions consist of a large proportion of shift work, and this may be a factor contributing to the limited, yet reduced HRV findings through the literature (Porges and Raskin, 1969). The hours worked by blue-collar workers may lead to behavioural changes such as smoking, poor diet, and less physical activity, which have known associations with CVD (Mosendane et al., 2008, Puttonen et al., 2010). Shift work also leads to desynchronization of circadian rhythms affecting the ability of the cardiovascular system to adapt to internal and external stimuli (Mosendane et al., 2008, Puttonen et al., 2010, Souza et al., 2015). Another theory suggests that the disruption of circadian rhythms that blue-collar workers may experience causes imbalances in the autonomic regulation of the heart and therefore increases the risk of CVD (Camm et al., 1996, Thayer et al., 2010).

4.2.2 Associations between Heart Rate Variability and Neurocognitive Performance in Blue-Collar Workers

At rest, higher parasympathetic activity (RMSSD) (vagal tone) indicated a better ability to detect sequences. This is supported by the literature stipulating better performance is associated with higher cardiac vagal tone (Thayer et al., 2009). Moreover, Hansen et al. (2003) examined sailors from the Royal Norwegian Navy (n = 53, average age = 23 years (range of 18-34 years)), looking at the effect of HRV on executive function performance, particularly working memory (WM) and sustained attention. The authors showed that better executive function was linked to higher HRV (Hansen et al., 2003). Contrastingly, Middleton et al. (1999) found a reduction of HRV during attentional tasks, especially in tasks that involved elements of working memory, in a normal, healthy sample (n = 32, average age = 24.6 years SD not specified, male = 17).

The blue-collar workers showed an inverse correlation between the LF/HF ratio and reaction time, and between LF and signal detection. Low frequency HRV, individually, has not only been associated with increased risk of CVD (Guzzetti et al., 1991) but also to poor executive function (Duschek et al., 2009). Given the contentious nature of LF through the literature (Reyes del Paso et al., 2013), some researchers suggest that the LF/HF ratio may be a better marker of the sympathovagal balance (Xhyheri et al., 2012). Despite being highly debated, reductions in the LF/HF ratio appears to show an imbalance between the branches of the autonomic nervous system geared towards sympathetic withdrawal and a rise in vagal modulation (Xhyheri et al., 2012). This increase towards vagal control (higher HF HRV) has been shown to be beneficial to both executive performance as well as cardiovascular health (Luft et al., 2009, Kubota et al., 2017). Supported by the current findings, given that LF HRV dominates, less sequences were detected by the blue-collar group. This is further supported by the finding that higher RMSSD is associated with a better ability to detect sequences, indicating a strong relationship between higher parasympathetic activity and improved performance. Moreover, as we consider these results, more evidence points towards better performance as the balance tips in favour of vagal control.

The differing relationships observed in the present study may be an indication of increased difficulty and mental load for the blue-collar workers when performing attentional and working memory performance tasks (Forte et al., 2019). There is a broad consensus that working memory and attention are closely related (Cowan, 1995, Olivers, 2008, Chun, 2011, Gazzaley and Nobre, 2012), however, the results of the current study suggest there may be differing underlying processes that govern them. In conceptualising the different theories, attention can be looked at as a resource, a form of storage and processing, and as a way to select what information is relevant (Oberauer, 2019). Moreover, working memory can provide a better understanding of what information is relevant and therefore kept, and which task sets are held and implemented to achieve immediate goals (Oberauer, 2019).

4.3 Conclusions: HRV and Neurocognitive Performance in Blue-Collar Workers

Overall, the blue-collar workers showed several significant changes in HRV as well as several correlations between HRV and neurocognitive performance. The differences in HRV found were reductions in LF HRV during SWM, and reductions in the RMSSD parameter of HRV during the AST whilst RMSSD increased during the RVP task. These findings corroborate the findings in the literature as HRV indices are known to be reduced in response to mental stress, workload, or increased executive function (Porges, 1995, Hansen et al., 2003). As previously mentioned, the contentions surrounding frequency HRV and the LF band has created some disparities in findings, however, it is strongly supported that increased LF HRV and reduced HF HRV are associated to worse performance as well as increased risk of various CVDs (Colhoun et al., 2001, Lombardi et al., 2001). Additionally, current findings in the blue-collar worker sample show various indices of HRV (LF, LF/HF, and RMMSD) being affected differently by independent variables (signal detection and reaction time). This points to the notion of different neurophysiological structures or pathways being responsible, irrespective of how interrelated attentional and memory processes may be (Porges, 1995, Thayer et al., 2009).

The present study also found that RMSSD HRV, an index of vagal tone, to be associated with better performance in the attention tasks, and this is supported by many previous studies (Hansen et al., 2003, Thayer et al., 2009, Forte et al., 2019). However, vagal tone was also related to worse performance in working memory performance, further supporting the idea that there are underlying differences in the neurophysiological processes which govern attention and working memory.

Studies have previously confirmed relationships between HRV and activity in prefrontal-subcortical pathways (Thayer and Lane, 2009, Sakaki et al., 2016). Most notably, higher resting HRV may be associated to increased activity in executive regions of the brain (Thayer et al., 2012) whilst lower baseline HRV is associated to hypo-activity in the prefrontal cortex (Park and Thayer, 2014). This implies that increased parasympathetic activity, or vagal modulation of the heart, may be associated with functional self-regulation of neural circuitry, which may allow an individual to respond more flexibly and effectively to various stimuli (Thayer et al., 2009, Thayer et al., 2012), and thus, allow for improved executive function.

Blue-collar professions are essential in the development and progress of the economy and infrastructure of a country, particularly in Australia. However, the very nature of the profession may predispose those individuals to CVD. In addition to the executive function associations, the shift work of blue-collar professions appears to have an association with CVD (Souza et al., 2015). HRV parameters observed to be reduced in blue-collar workers include HF, RMSSD, and LF (Souza et al., 2015), all of which previous research has deemed to be a risk for developing CVD (Thayer et al., 2010). Hulsegge et al. (2018) observed reduced HRV in male but not in female blue-collar workers (n = 665, average age = 45.5 ± 9.7 years, 56% male) however, they did not find an association to the overall cohort, suggesting gender predisposition to differences in HRV and CVD within the blue-collar worker population.

Chapter 5 HRV and Neurocognitive Performance: Comparison of White- and Blue-Collar Workers

5.1 Results: White-Collar versus Blue-Collar Workers

This chapter presents the results from the comparison of the white-collar (n = 48) and blue-collar (n = 53) worker sample groups, representing a total sample of n = 101 workers. Independent sample t-tests were used to examine differences in demographic variables (Section 5.1.1), neurocognitive performance (Section 5.1.2), and HRV parameters (Section 5.1.3).

5.1.1 Demographics: White-Collar and Blue-Collar Workers

An independent sample t-test of the demographic data between the white- (n = 48) and blue-collar (n = 53) workers identified that the white-collar worker sample spent significantly more years on education than blue-collar workers (4.33 ± 1.20 years and, 3.4 ± 1.2 years, respectively; $t = 3.99$, $df = 99$, $p < 0.001$).

5.1.2 Differences in Neurocognitive Performance between White-Collar and Blue-Collar Workers

The differences in neurocognitive performance between the white-collar and blue-collar workers are presented here. The outcome measures were assessed during the spatial working memory (SWM), attention switching task (AST), rapid visual processing (RVP) task, and spatial span (SSP) task.

Independent sample t-tests were performed to identify any differences in neurocognitive performance measures between the white-collar (n = 48) and blue-collar (n = 53) worker sample groups. The significant findings are summarised in Table 5.1.

Attention Switching Task

During the AST, it was found that the white-collar worker group made less errors when the cue given was incongruent as compared to the blue-collar worker group (8 ± 3.14 and, 9.4 ± 3.62, respectively) (t = -2.06, df = 99, p = 0.04). However, when the "side" cue was given the white-collar group made more errors than the blue-collar group (4.33 ± 2.56 and, 3.19 ± 2.16, respectively) (t = 2.44, df = 99, p = 0.02). Moreover, the white-collar group made significantly more correct responses than the blue-collar group overall (144.20 ± 8.53 and, 139.43 ± 9.80, respectively) (t = 2.6, df = 99, p = 0.01).

Rapid Visual Processing

Throughout the RVP task, the ability to detect signals was significantly higher in the white-collar group as compared to the blue-collar group (0.90 ± 0.08 and, 0.85 ± 0.08, respectively) (t = 3.14, df = 99, p = 0.002).

Spatial Span

Finally, the SSP task saw the white-collar group make more total errors than the blue-collar group (13.48 ± 5.65 and, 9.74 ± 6.55, respectively) (t = 3.06, df = 99, p = 0.003).

Table 5.1 Independent Sample t-test Comparing Neurocognitive Performance Measures between the Blue- (n = 53) and White-collar (n = 48) Worker Groups

Task	Variable	F	df	p	White-collar mean ± SD	Blue-collar mean ± SD	Mean Difference (white-blue)
AST	Incongruent Errors	1.25	99	0.04	8 ± 3.14	9.4 ± 3.62	-1.4
	Errors (side)	3.21	99	0.02	4.33 ± 2.56	3.19 ± 2.16	1.14
	Total Correct	0.03	99	0.01	144.20 ± 8.53	139.43 ± 9.80	4.77
RVP	Signal Detection	0.03	99	0.002	0.90 ± 0.08	0.85 ± 0.08	0.05
SSP	Total Errors	1.30	99	0.003	13.48 ± 5.65	9.74 ± 6.55	3.74

Table 5.1 displays the significant differences found from an independent sample t-test between the white- (n = 48) and blue-collar (n = 48) worker groups for neurocognitive performance measures across all tasks, where significance is determined by $p < 0.05$.

Key: AST = Attention switching task; df = Degrees of freedom; F = F statistic; n = Sample size; p = Level of statistical significance ($p < 0.05$); RVP = Rapid visual processing; SD = Standard deviation; SSP = Spatial span

5.1.3 Differences in HRV Parameters between the White-Collar and Blue-Collar Workers

Independent sample t-tests were used to compare HRV parameters between the white- and blue-collar worker groups. The amount of variation in cardiac activity was also compared. This change in cardiac response is referred to as cardiac reactivity (CR) and is determined by active phase (neurocognitive performance tasks) HRV minus baseline HRV. Table 5.2 summarises the significant findings.

Spatial Working Memory

Throughout the Spatial Working Memory (SWM) task, the white-collar worker group, compared to the blue-collar worker group, had significantly higher log LF (6.33 ± 0.60 and, 6.01 ± 0.48, respectively) ($t = 2.93$, $df = 99$, $p = 0.004$), significantly lower log LF/HF (1.61 ± 0.83 and, 1.22 ± 0.84, respectively) ($t = 2.35$, $df = 99$, $p = 0.02$), significantly higher log TP (6.7 ± 0.52 and, 6.48 ± 0.37, respectively) ($t = 2.42$, $df = 99$, $p = 0.02$), and significantly lower log LF/HF cardiac reactivity (-0.08 ± 0.74 and, -0.32 ± 0.47, respectively) ($t = 2.59$, $df = 99$, $p = 0.01$).

Attention Switching Task

During the Attention Switching Task (AST), the white-collar worker group had significantly higher mean RR cardiac reactivity (4.7 ± 3315 and -11.84 ± 34.2, respectively) ($t = 2.44$, $df = 99$, $p = 0.02$) and log RMSSD cardiac reactivity (0.005 ± 0.04 and, -0.02 ± 0.04, respectively) ($t = 2.45$, $df = 99$, $p = 0.02$).

Rapid Visual Processing

The Rapid Visual Processing (RVP) task, highlighted significantly lower HRV parameters in the white-collar worker group vs the blue-collar worker group, particularly, log LF (6.16 ± 0.47 and 6.44 ± 0.33, respectively) ($t = -3.47$, $df = 79.87$, $p < 0.001$), log HF (5.04 ± 0.60 and 5.28 ± 0.42, respectively) ($t = -2.23$, $df = 78.51$, $p = 0.03$), log TP (6.61 ± 0.44 and 6.89 ± 0.27, respectively) ($t = -3.73$, $df = 74.72$, $p < 0.001$), log SDNN (3.39 ± 0.22 and 3.53 ± 0.12, respectively) ($t = -3.82$, $df = 68.19$, $p < 0.001$), log LF cardiac reactivity (-0.39 ± 1.08 and 0.11 ± 0.45, respectively) ($t = -3.08$, $df = -2.97$, $p = 0.004$), log HF cardiac reactivity (-0.31 ± 1.18 and 0.22 ± 1.1, respectively) ($t = -2.12$,$df = 99$, $p = 0.04$), log TP cardiac reactivity (-0.4 ± 1.21 and 0.04 ± 0.65, respectively) ($t = -2.18$, $df = 99$, $p = 0.03$), and log SDNN cardiac reactivity (3.39 ± 0.22 and 3.53 ± 0.12, respectively) ($t = -2.17$,$df = 47.33$, $p = 0.03$).

Spatial Span

During the Spatial Span (SSP) task, it was found that log HF was significantly lower in the white-collar worker group as compared to the blue-collar worker group (4.81 ± 0.58 and, 5.07 ± 0.67, respectively) ($t = -2.14$, $df = 98$, $p = 0.03$).

Table 5.2 Independent Sample t-test of HRV between the White- (n = 48) and Blue-collar (n = 53) Worker Sample

Task	Variable	F	df	p	White-collar mean ± SD	Blue-collar mean ± SD	Mean Difference (white-blue)
SWM	Log LF (ms^2)	0.69	99	0.004	6.33 ± 0.60	6.01 ± 0.48	0.31
	Log LF/HF	0.66	99	0.02	1.61 ± 0.83	1.22 ± 0.84	0.39
	Log TP (ms^2)	1.59	99	0.02	6.7 ± 0.52	6.48 ± 0.37	0.22
	Log CR LF/HF	0.96	99	0.01	-0.08 ± 0.74	-0.32 ± 0.47	0.24
AST	CR mean RR (ms)	0.30	99	0.02	4.7 ± 33.15	-11.84 ± 34.2	16.53
	Log CR RMSSD (ms)	0.21	99	0.02	0.005 ± 0.04	-0.02 ± 0.04	0.02
RVP	Log LF (ms^2)	5.41	79.87	<0.001	6.16 ± 0.47	6.44 ± 0.33	-0.29
	Log HF (ms^2)	7.84	78.50	0.03	5.04 ± 0.60	5.28 ± 0.42	-0.233
	Log TP (ms^2)	11.72	74.72	<0.001	6.61 ± 0.44	6.89 ± 0.27	-0.28
	Log SDNN (ms)	11.1	-3.82	<0.001	3.39 ± 0.22	3.53 ± 0.12	-0.14
	Log CR LF (ms^2)	3.13	-2.97	0.004	-0.39 ± 1.09	0.11 ± 0.46	-0.5
	Log CR HF (ms^2)	0.07	99	0.04	-0.31 ± 1.20	0.22 ± 1.11	-0.5
	Log CR TP (ms^2)	0.13	99	0.03	-0.4 ± 1.23	0.04 ± 0.66	-0.4
	Log CR SDNN (ms)	12.02	47.33	0.03	-0.19 ± 0.65	0.01 ± 0.04	-0.2
SSP	Log HF (ms^2)	0.67	98	0.03	4.81 ± 0.58	5.07 ± 0.67	-0.27

Table 5.2 displays the significant results from an independent sample t-test between the white- (n = 48) and blue-collar (n = 53) worker groups, where significance is determined by $p < 0.05$.

Key: CR = Cardiac reactivity; df = Degrees of freedom; F = F statistic; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Low frequency divided by high frequency; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample Size; p = Level of statistical significance ($p < 0.05$); RVP = Rapid visual processing; SD = Standard deviation; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span; SWM = Spatial working memory; TP = Total power

5.2 Discussion: Comparison of White-Collar and Blue-Collar Workers

This chapter presented, and will now discuss, the differences in HRV and neurocognitive performance between the blue- and white-collar workers (Chapter 1.7, Aim 3). It was hypothesised that differences in both HRV parameters and neurocognitive performance measures would be observed between the blue- and white-collar worker groups (Chapter 1.8, Hypotheses 3 and 4), and the results presented show that the hypotheses were accepted.

The current literature comparing these two sub groups is very limited, however, early work by Myrtek et al. (1999) investigated the level of stress and strain and its relationship to heart rate, physical activity, emotional strain, and mental strain. The authors found no differences in variability of heart rate (HR) between the two groups, however, they did find that white-collar workers were more stressed, subjectively (Myrtek et al., 1999). Additionally, it is thought that blue-collar workers are subject to increased physical workload and white-collar workers have high mental workload, and although, interviews and questionnaires supported this idea, the physiological measurements did not (Myrtek et al., 1999).

Early work in the literature highlights conflicting evidence between blue- and white-collar workers, and which type of worker is more predisposed to CVD where some studies suggest blue-collar workers are more at risk (Buring et al., 1987, Nakamura et al., 2000, Voelker, 2014) while others suggest white-collar workers are more at risk (Prihartono et al., 2018). Moreover, there is very little research investigating HRV parameters, neurocognitive performance measures, and their associations with CVD in these two cohorts, and so, the present research may provide more information and data regarding the relationship between different occupational and physiological risk measures, and CVD.

The only statistically significant differences in demographics came from the years spent on education where the blue-collar workers spent less time in formal education. Interestingly, Prihartono et al. (2018) found that the increased level of education of white-collar workers significantly increased the prevalence of CVD. Moreover, prevalence of CVD by diagnosis was higher in the white-collar worker population, while the prevalence by symptoms was higher among the blue-collar worker group (Prihartono et al., 2018). Even though the blue-collar workers are inherently more physically active in their day-to-day work, the socio-economic status and lifestyle choices may have a significant impact, particularly in the available access to health care. With lower education and lower salaries this population group are more likely to be exposed to unhealthy lifestyle choices (Clougherty et al., 2010). Additionally, the literature has shown that a higher BMI indicated an increased prevalence of CVD in both blue- and white-collar workers, hypertension showed a 1.6 times increased likelihood of CVD, and diabetes was the strongest risk factor showing a 3 to 5 times greater prevalence of CVD in the workers (Conen et al., 2007, Prihartono et al., 2018).

5.2.1 Differences in Heart Rate Variability Parameters between the White-Collar and Blue-Collar Workers during the Neurocognitive Tasks

Spatial Working Memory

During the SWM task, LF, LF/HF, and TP parameters of HRV were all greater in the white-collar worker group as compared to the blue-collar worker group. LF HRV was traditionally thought to reflect sympathetic activity, as previously mentioned however, recent research indicates it has influence from both the sympathetic and parasympathetic branches of the ANS (Berntson et al., 2007, Reyes del Paso et al., 2013). This increase in LF HRV activity may point to increased sympathetic activity and dominance during these tasks for the white-collar group. This finding has been previously associated with an increased risk in CVD (Guzzetti et al., 1991, Hamaad et al., 2005). This has also been contrasted by other literature reporting that low LF HRV was associated to certain risk factors which predispose to CVD, such as, hypertension (Thayer et al., 2010). Moreover, a review by Hillebrand et al. (2013) highlighted that low HRV indices, including LF HRV, indicated a higher risk of CVD in populations without any prior CVD. Interestingly, much of the previous research indicates that vagal withdrawal, and therefore an increased sympathetic response, is responsible for the cardiovascular disease risks (Carnevali et al., 2013, Liu et al., 2019). However, Hamaad et al. (2005)

provides a differing perspective, suggesting that it is sympathetic activation which may be associated to cardiac events, not the former. Hamaad et al. (2005) investigated the associations between indices of HRV (time and frequency) and inflammatory biomarkers in patients with acute coronary syndrome (n = 100, male = 77, average age = 63 ± 12 years) and healthy controls (n = 49, male = 32, average age = 60 ± 10 years). Though the correlations were modest, the authors reported an inverse relationship between LF HRV and inflammatory biomarkers and therefore implicate sympathetic tone in CVD (Hamaad et al., 2005). This idea is further supported by several studies which further investigate the inflammatory biomarkers and associated HRV changes (Malave et al., 2003, Shehab et al., 2004, Lanza et al., 2006, Psychari et al., 2007).

Attention Switching

The AST showed significantly lower cardiac reactivity (CR) (active minus baseline) mean RR and CR RMSSD in the blue-collar workers. A larger CR refers to increased time periods between the RR intervals and therefore shows a slower HR (Fleiss et al., 1992), whilst decreased CR indicates less time between RR intervals and therefore higher HR. In an assessment of working memory, Capuana et al. (2014) found that pre-task HR is associated with better executive function (n = 17, female = 11, age = 18-26 years). Moreover, as cognitive load increased so did the reaction times and errors of both the older aged (n = 18, female = 11, age = 65-83 years) and younger participants (n = 22, female = 17, age = 18-27 years) with participants also showing increased cardiac workload (Capuana et al., 2012). Thus, the authors suggest that a broader perspective of cardiac workload as a whole should also be contemplated (Capuana et al., 2012). This further supports the notion that attentional control should also be considered from a broader perspective that encompasses the relationship between executive function and autonomic cardiac regulation.

Rapid Visual Processing

The RVP (rapid visual processing) task showed the blue-collar workers to have higher HRV parameters across the board, particularly LF, HF, TP, and SDNN. This is an interesting finding as the RVP task is one of sustained attention, and it was therefore expected that the white-collar worker group would exhibit higher levels of cardiac vagal control, or parasympathetic activity, as indexed by HF HRV. SDNN (time domain) and TP HRV (frequency domain) are markers of overall HRV, whereby reduced values, particularly SDNN, have indicated increased risk of CVD (Xhyheri et al., 2012). Furthermore, the body of research regarding occupational stress, HRV, and cardiovascular disease is one that is constantly growing (Clays et al., 2011, Backe et al., 2012, Charles et al., 2014). Predominantly, what is being shown is reduced parasympathetic activity as a result of occupational stress (Collins et al., 2005, Clays et al., 2011). The findings of the present research may reflect high levels of stress within the white-collar worker population as shown by lower HF HRV (parasympathetic activity). Previous literature concluding which occupational group is more stressed is contentious but suggests a multifaceted approach to determining the influences (Dėdelė et al., 2019). Dėdelė et al. (2019) indicates that blue-collar workers are 1.5 times more likely to perceive higher levels of stress in general. However, the white-collar workers had a 4 times increased likelihood of perceiving greater stress when being sedentary for more than 3 hours per day (Dėdelė et al., 2019). Contrastingly, Nydegger (2011) found no significant difference in stress levels between blue- and white-collar workers, nor any differences between genders. Given these studies only assessed perceived stress by way of surveys, the results may be too subjective and susceptible to various factors influencing the responses. Therefore, having a more objective measure would have been of great benefit to support their findings. Notwithstanding, they do provide grounds to indicate an intricate system of relationships between workplace stress, HRV, and CVD. Moreover, recommendations made to white-collar workers include improvements in the sedentary lifestyle and increasing physical activity during work hours, while recommendations to the blue-collar workers include avoiding the unhealthy lifestyle habits (Collins et al., 2005, Clays et al., 2011, Nydegger, 2011, Dėdelė et al., 2019). These practices will reduce stress, improve cardiac autonomic activity and parasympathetic input, and ultimately, reduce the risk of a cardiovascular event.

The RVP task also saw significantly lower CR for LF, HF, TP, and SDNN HRV in the white-collar workers. As previously mentioned, it is widely accepted that high vagal tone and CR are markers for strong cardiac health and low vagal tone predisposes to a variety of CVDs and mortality (Thayer et al., 2010). However, what is less understood and explored is the relationships that exist between CR and neurocognitive performance, especially with the lack of research in HRV reactivity. Previous research has studied HR and respiratory sinus arrhythmia (RSA) reactivity and it is possible to draw comparisons to HRV as reduced HR, increased RSA, and increased HRV indicate better cardiac vagal control (Kimhy et al., 2013, Overbeek et al., 2014). The study performed by Kimhy et al. (2013) investigated the relationship between cardiac vagal control and executive function (n = 817, average age = 57.11 ± 11.15 years, male = 44%). Their results of HRV and RSA, while adjusting for respiration, indicated that better cardiac vagal control is associated with better performance on attention tasks, and response inhibition (Kimhy et al., 2013). This further solidifies that better vagal activity, indexed by HRV, is strongly associated with better executive function. Additionally, Capuana et al. (2014) showed that better cardiac vagal modulation, indexed by RSA, reflected more accurate functioning of the prefrontal cortex (PFC) and therefore, better performance on the Stroop task (Stroop, 1935a). Contrastingly, Overbeek et al. (2014) studied the effects of cognitive and attentional demands on RSA in two age groups, young (n = 42, average age = 19.81 ± 1.89, female = 50%) and middle aged (n = 41, average age 45.76 ± 7.34). The authors noted that a decline in RSA was associated with working memory, while increased vagally mediated control was beneficial for attention (Overbeek et al., 2014). This demonstrates the complex relationship that exists between HRV and neurocognitive performance which further warrants studies like the present one where individual indices of HRV, in both time and frequency domains, are explored.

Spatial Span

The final difference in HRV between the blue- and white-collar groups was during the SSP task. The blue-collar group showed higher vagal mediation than the white-collar group, which is indicative of better control and better performance. Moreover, it may indicate a more relaxed scenario as the SSP task is designed to test working memory capacity in the 3D space around them, an environment familiar to blue-collar workers.

The literature has indicated several main findings when assessing HRV in different occupational settings. Among white-collar workers, the HRV parameters most affected seem to be LF, HF, and SDNN (Kobayashi et al., 2001, Watanabe et al., 2002, Hemingway et al., 2005). A study of 2197 civil servants (100% male, aged between 35 and 55 years), mixed blue- and white-collar jobs, found the most significant finding affecting HRV was low employment grade (Hemingway et al., 2005), where lower employment grade was associated with low SDNN, HF, and LF HRV. Furthermore, Kobayashi et al. (2001) performed a study on male white-collar workers comparing hypertensive (n = 11, average age = 33.4 ± 4.2 years) and normotensive (n = 11, average age = 33.5 ± 4.0 years) individuals. Authors found that the hypertensive group showed significantly reduced parasympathetic control during sleep, and significantly increased sympathetic dominance while at work, as compared to the normotensive group (Kobayashi et al., 2001). Moreover, another study of middle aged white-collar male workers indicated that overtime and business trips were associated with lower HF HRV (n = 52, aged between 30-55 years) (Watanabe et al., 2002).

For the blue-collar workers, previous literature indicates a separate set of findings. Sasaki et al. (1999) studied the occupational effects of engineering in machinery manufacturing and found a sympathetic dominance (increased LF/HF HRV) during rest and fatigued states with increasing hours. In addition, the effects of fatigue were followed by Pichot et al. (2002) in a study of blue-collar garbage collectors (n = 6, aged 32.1 ± 4.3 years, male = 100%) in which HRV was tested over 3 consecutive weeks. The authors reported a significant and progressive decrease in HRV indices, namely mean RR, RMSSD, LF, and HF (Pichot et al., 2002). It is also important to note that with many blue-collar professions there are significant mental and physical workloads. For example Myrtek et al. (1994) assessed the physical, emotional, mental, and subjective workload of train drivers on a high speed track (n = 12, average age = 50.7 years, gender unspecified) and drivers on a mountain track (n = 11, average age = 43.0 years, gender unspecified) during a normal working day. As drivers went from 100km/hr to 200km/hr, RMSSD was found to decrease. This indicated a state of monotony as the train begins to be more computer controlled, and authors warned that the drivers may not be able to react appropriately in this reduced state of activation (Myrtek et al., 1994). One of the most significantly researched areas for blue-collar workers is that of shift work and HRV (Ito et al., 2001). Shift work is known to alter circadian rhythms and therefore may influence HRV, and so research has indicated detrimental effects on cardiovascular parameters (Ha et al., 2001, Ishii et al., 2005). Contrastingly, Ito et al. (2001) studied nurses (n = 10, aged 33 ± 3, 100% female) and found no significant differences between day shifts and nights shifts. However, this particular finding may show different results with an increased sample size as well as a comparison to non-shift workers. This idea is supported by multiple studies indicating that shift work does in fact serve as a detriment to cardiovascular health (Ha et al., 2001, Lee et al., 2015).

5.2.2 Comparison of Neurocognitive Performance between the White-Collar and Blue-Collar workers

Occupation has been considered as an important predictor of cognitive ability and decline over time (Helmer et al., 2001, Nguyen et al., 2008). Furthermore, the executive function requirements in the workplace, as well as the complexities of the environment, seem to have a correlation to cognitive decline (Finkel et al., 2009). Prior research seems to have focused on the age-related decline in cognitive processing and few studies have focused on the occupational effects. However, given that people spend a substantial portion of life at work, the workplace environment may have a significant effect (Then et al., 2014).

Attention Switching

The AST showed the white-collar workers to make less errors when the cues were changing and more errors when the "side" cue was given. However, in the task as a whole, the white-collar workers gave significantly more correct responses than the blue-collar workers. In a longitudinal study spanning 10 years, Kim et al. (2020) assessed executive function in blue- (n = 1216, 61% Female, aged 70.7 ± 4.64 years) and white-collar workers (n = 242, 22% Female, aged 69.98 ± 4.18 years). The authors gathered data using the Mini-Mental Sate Examination (MMSE) (Folstein et al., 1975) and other potential covariates including sociodemographic factors, health related factors, and occupational factors (Kim et al., 2020). Primary findings between the longest-held lifetime occupation and executive function decline showed that males had no significant risks whilst females showed a 2.5-fold increased risk of cognitive impairment in blue-collar workers compared to white-collar workers (Kim et al., 2020).

Rapid Visual Processing/Spatial Span

The white-collar workers showed significantly better performance during the RVP task, where their ability to detect sequences was much better. However, the white-collar workers made more errors during the SSP task. The relationship between mental workload and cardiovascular parameters is further illustrated by Capuana et al. (2012). These authors assessed 22 young adults (17 women, 18-27 years, average age = 20.5 years (SD not specified)) and 18 older adults (11 women, 65-83 years, average age = 72.3 (SD not specified)) and indicated relationships between cardiac measures and performance as well as an association between increased cardiac workload and more errors in the older adults but not the younger adults (Capuana et al., 2012). This further supports and adds to the age-related literature regarding neurocognitive performance with the added element of cardiac risk measures. The results of previous literature and the present findings suggest that the effects of occupation on executive functions are multifaceted (Nguyen et al., 2008). Prior research has indicated white-collar workers to be cognitively more inclined in the later years (Nguyen et al., 2008). Moreover, manual labour workers (e.g., machine operators, assembly workers, and plant operators) have been shown to have a significantly higher chance of reduced executive function as compared to non-manual labourers (e.g., business executives, administrators, and managers) (Dartigues et al., 1992, Li et al., 2002). The white-collar workers seem to have performed better on the executive function tasks. Notwithstanding, the varying performance on different tasks, an in-depth analysis is required to supplement broader examinations to identify specific relationships between cardiac variables and neurocognitive performance measures.

Several factors may be considered when assessing the performance and risks of the blue- and white-collar worker populations. Most people spend a large portion of their life at work, and the inherent risks related to employment are factors that require further research. These risks may be a result of complexity in those given occupations, a concept which was first touched upon by Schooler (1984) and further by Schooler et al. (2004). These authors suggested that complex environments at work, or during leisure time, allows for continued reinforcement of executive functioning. This greater intellectual stimulation increases neural growth and synaptic density which protects against cognitive decline (Alvarado et al., 2002). Therefore, lower intellectual demand for blue-collar workers may predispose them to executive function impairments. This is just one facet by which the literature suggests the superior ability of white-collar workers. Another theory indicates that since blue-collar work is associated with a lower income, this translates to poor housing, nutrition, environment, and poor lifestyle habits and practices, which may be linked to cognitive decline (Lee et al., 2010, Zhang et al., 2015). Interestingly, white-collar workers are more educated in the traditional sense, but this does not necessarily reflect in overall intelligence. Given that white-collar workers are known to use cognitive abilities more often than blue-collar workers, it could be assumed that they have superior cognitive abilities. This may not be the case however, as a study showed no evidence that regular use of computerised brain trainers improves general cognitive functioning (Owen et al., 2010).

5.3 Conclusion: Comparison of HRV and Neurocognitive Performance Measures in White-Collar Workers and Blue-Collar Workers

These days, the line between blue- and white-collar jobs is increasingly becoming blurred where previously the roles were well defined (Lips-Wiersma et al., 2016). Overall, the present research identified multiple significant differences and associations between HRV parameters and neurocognitive performance measures in the blue- and white-collar worker groups. As a whole, the white-collar worker group showed higher cardiac measures (indexed by HRV) during spatial working memory and attention switching tasks while showing lower cardiac modulation during sustained attention and memory capacity. The variations observed are indicative of a complex and intricate neurophysiological network of processes coming together to execute on performance. The ability of an individual may be related to initial intelligence, however, the inherent tasks, day-to-day, may also alter health and neurocognitive performance over an individual's lifetime. Therefore, the reduced executive function later in life, with its associations to various cardiac vagal modulation, may make workers more susceptible to cardiovascular events. The current findings also suggest that future studies should perform more in-depth analyses when assessing cardiac autonomic regulation and neurocognitive performance with individual indices of HRV and components of executive functions being taken into consideration.

As it was found that white-collar workers had lower HRV indices than blue-collar workers, this may predispose them to CVD. Interestingly, Hillebrand et al. (2013) performed a meta-analysis and dose-response meta-regression, (8 studies in total from 3613) encompassing a total of 21988 participants (age range of 26 - 80 years, percentage of females ranged from 0-64%) and showed that low HRV is associated with a 32-45% increased risk of a first cardiovascular event occurring in populations without known CVD. Moreover, Hallman et al. (2015) demonstrated that blue-collar worker's HRV was reduced by those who were sitting down more often during work. Additionally, these workers had attenuated RMSSD and TP HRV, indicating reduced vagal tone and baroreceptor-sympathetic activation, and therefore, an increased risk of CVD (Hallman et al., 2015). It was also shown that blue-collar workers were 40% more likely to report a history of CVD as compared to white-collar workers (Voelker, 2014). The authors then narrowed down their findings and reported two main industry groups that are most at risk, accommodation and food services, and administrative/support/ waste management workers (Voelker, 2014).

Cognitive training has become increasingly used in the workplace as it may be beneficial for workplace productivity (Borness et al., 2013), moreover, the impact of simply taking more time-outs or breaks during the work day has received a lot of support (Tucker, 2003). Work day breaks have been shown to counter the effects of fatigue and increase productivity among workers (Tucker, 2003). Moreover, these breaks have important implications in the recovery process (Trougakos and Hideg, 2009). Additionally it seems that workplace interventions are targeting mental health as opposed to cognition alone (Borness et al., 2013). This continues to suggest that there is a multifaceted relationship between the profession, neurocognitive performance, and CVD.

Ultimately, what we are seeing is reduced parasympathetic modulation of the heart, particularly in white-collared workers, as a result of occupational stress in its subjective and objective forms (Collins et al., 2005, Clays et al., 2011). Previous research has attempted to conclude which professions are most at risk, some suggesting white-collar workers (Prihartono et al., 2018) and others suggesting blue-collar workers (Sasaki et al., 1999, Pichot et al., 2002), to no avail. Due to the complicated neurocortical processes required to perform various tasks, perhaps a judgement cannot be made as to which professions are more susceptible, but rather, what type of tasks performed over our lifetime influence cardiac autonomic activity the greatest.

Chapter 6 Comparison of High HRV and Low HRV Groups within the Blue-Collar and White-Collar Cohorts

6.1 Median Split

This chapter presents a comparison between the high and low HRV groups within the blue- and white-collar sample. Median splits were performed on the basis of RMSSD, HF, and LF/HF (sympathovagal balance) values (Hansen et al., 2003). This allowed for a comparison of neurocognitive performance between the low HRV and high HRV groups. The literature has consistently emphasised an association between high HRV and better cognitive performance as well as better cardiovascular health (Hansen et al., 2003, Hillebrand et al., 2013, Colzato et al., 2018) and hence, this differentiation between high HRV and low HRV was further examined.

Section 6.2 presents the differences in neurocognitive performance (Section 6.2.1) and differences in correlations (Section 6.2.2) between high HRV and low HRV within the white-collar group, whilst Section 6.3 presents these differences (6.3.1) and correlations (6.3.2) within the blue-collar group.

The heart rate variability splits were performed around the median based on 3 different variables. RMSSD indicates vagally mediated cardiac control which correlates highly with high frequency (HF) HRV, both of which are robust in their representation of the parasympathetic nervous system (Thayer et al., 2000). The LF/HF ratio (sympathovagal balance) indicates the relationship between sympathetic and parasympathetic activity. Hansen et al. (2003) performed a median split only based on the RMSSD parameter of HRV, however, given the strong correlations that exist between the aforementioned HRV parameters, these 3 variables; RMSSD, HF, and LF/HF, were the basis of the median splits performed.

As shown below in Table 6.1, the white-collar group had a median of 20.44 ms for RMSSD, 6.69 ms for log RMSSD, 161.16 ms^2 for HF, 5.07 ms^2 for log HF, 4.45 for LF/HF, and 1.49 for log LF/HF. As displayed in Table 6.2, the blue-collar group had a median of

18.65 ms for RMSSD, 6.69 ms for log RMSSD, 101.72 ms^2 for HF, 4.62 ms^2 for log HF, 6.22 for LF/HF, and 1.83 for log LF/HF.

Table 6.1 Medians for HRV Split of the White-collar Worker Group into High and Low HRV Sub-Groups

Variable	Median	No. in High Group	No. in Low Group
RMSSD (ms)	20.44	n = 24 (n = 50%)	n = 24 (n = 50%)
Log RMSSD (ms)	6.69	n = 20 (n = 41.7%)	n = 28 (n = 58.3%)
HF (ms^2)	161.16	n = 24 (n = 50%)	n = 24 (n = 50%)
Log HF (ms^2)	5.07	n = 24 (n = 50%)	n = 24 (n = 50%)
LF/HF	4.45	n = 24 (n = 50%)	n = 24 (n = 50%)
Log LF/HF	1.49	n = 24 (n = 50%)	n = 24 (n = 50%)

Table 6.1 reports the median split values for the white-collar worker group and the number of participants that were placed in the high and low HRV groups.

Key: HRV = Heart rate variability; HF = High frequency; LF/HF = Low frequency to high frequency ratio; n = Sample size; No. = Number; RMSSD = Root mean squared of successive differences

Table 6.2 Medians for HRV Split of the Blue-collar Worker Group into High and Low HRV Sub-Groups

Variable	Median	No. in High Group	No. in Low Group
RMSSD (ms)	18.65	n = 25 (n = 47.2%)	n = 28 (n = 52.8%)
Log RMSSD (ms)	6.69	n = 24 (n = 45.3%)	n = 29 (n = 54.7%)
HF (ms^2)	101.72	n = 26 (n = 49.1%)	n = 27 (n = 50.9%)
Log HF (ms^2)	4.62	n = 26 (n = 49.1%)	n = 27 (n = 50.9%)
LF/HF	6.22	n = 25 (n = 47.2%)	n = 28 (n = 52.8%)
Log LF/HF	1.83	n = 25 (n = 47.2%)	n = 28 (n = 52.8%)

Table 6.2 reports the median split values for the blue-collar worker group and the number of participants that were placed in the high or low HRV group.

Key: HRV = Heart rate variability; HF = High frequency; LF/HF = Low frequency to high frequency ratio; n = Sample size; No. = Number; RMSSD = Root mean squared of successive differences

6.2 Results: Comparison of High HRV versus Low HRV in White-Collar Workers

6.2.1 Differences in Neurocognitive Performance between High and Low HRV (White-Collar Workers)

Mann-Whitney U tests were used to compare the neurocognitive performance scores between the high HRV groups and the low HRV groups for the white-collar workers (Table 6.3). This showed that the high RMSSD group (high = 2.25 ± 2.24, low = 3.5 ± 2.35) made less mistakes when the "side" cue was given during the AST and the high log RMSSD group made less errors in the SSP task as compared to the low log RMSSD group, respectively (1.08 ± 1.2, 2.08 ± 1.44).

Conversely, the high HF group (high = 5.17 ± 2.44, low = 3.5 ± 2.35) and high log HF (high = 5.17 ± 2.44, low = 3.5 ± 2.35, respectively) group made more errors during the "side" cue in the AST.

Table 6.3 Mann-Whitney U Test Comparing Neurocognitive Performance between the High and Low HRV Sub-Groups Within the White-collar Group (n = 48)

HRV Split	Variable	U	Z	p	High HRV Mean ± SD	Low HRV Mean ± SD	Mean Difference (high HRV - low HRV)
RMSSD M = 20.44 (ms)	Errors (side)	183	-2.18	0.03	2.25 ± 2.24	3.5 ± 2.35	-1.25
Log RMSSD M = 6.69 (ms)	Errors (not next in sequence)	173	-2.43	0.02	1.08 ± 1.2	2.08 ± 1.44	-1
HF M = 161.16 (ms^2)	Errors (side)	183	-2.18	0.03	5.17 ± 2.44	3.5 ± 2.35	1.67
Log HF M = 5.07 ms^2	Errors (side)	183	-2.18	0.03	5.17 ± 2.44	3.5 ± 2.35	1.67

Table 6.3 shows the results of the Mann-Whitney U tests performed to compare the neurocognitive performance scores between the high and low HRV sub-groups within the white-collar group. The HRV parameter splits that showed significance ($p < 0.05$) were, RMSSD, log RMSSD, HF, and log HF.

Key: HRV = Heart rate variability; HF = High Frequency; M = Median; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; p = level of significance ($p < 0.05$); RMSSD = Root mean squared of successive differences; SD = Standard deviation; U = U test statistic; Z = Z score

6.2.2 Correlations between HRV and Neurocognitive Performance Measures in the High and Low HRV (White-Collar Workers)

Correlations were performed to determine which associations were significantly related to dependent and independent variables. Specifically, Spearman's bivariate analyses were performed between the high HRV group and neurocognitive performance, and between the low HRV group and neurocognitive performance measures. As previously mentioned, the HRV parameters that were split were log RMSSD (parasympathetic activity), log HF (parasympathetic activity), and log LF/HF (sympathovagal balance) (Table 6.4, Table 6.5, and Table 6.6, respectively).

Log RMSSD

With a median of 6.69 (ms), the high log RMSSD group (Table 6.4) showed positive correlations between log RMSSD and total errors during the AST ($r = 0.41$, $p = 0.049$). A positive relationship was also found in the RVP task between log SDNN and reaction time ($r = 0.6$, $p = 0.04$), log LF and reaction time ($r = 0.8$, $p < 0.01$), log HF and reaction time ($r = 0.9$, p 0.01), and log TP and reaction time ($r = 0.54$, $p < 0.001$). The high RMSSD group also showed a negative correlation between log LF/HF and reaction time ($r = -0.42$, $p = 0.04$) in the AST.

The low log RMSSD group (Table 6.4) showed negative associations between log SDNN and reaction time ($r = -0.43$, $p = 0.04$), log TP and reaction time (-0.46, $p = 0.02$), and also during the SWM task between log HF and errors on the 4-box trial ($r = -0.41$, $p = 0.045$).

Table 6.4 Spearman's Correlation between HRV and Neurocognitive Performance Measures in the High and Low Log RMSSD Groups (White-collar Workers)

Log RMSSD Median = 20.44 (ms)	Task	Dependent Variable	Independent Variable	r	p
High n = 24	AST	Log RMSSD	Total Incorrect	0.41	0.049
		Log LF/HF	Reaction Time (correct)	-0.42	0.04
	RVP	Log SDNN	Reaction Time (correct)	0.6	0.002
		Log LF	Reaction Time (correct)	0.8	0.005
		Log HF	Reaction Time (correct)	0.9	0.01
		Log TP	Reaction Time (correct)	0.54	<0.001
Low n = 24	RVP	Log SDNN	Reaction Time (correct)	-0.43	0.04
		Log TP	Reaction Time (correct)	-0.46	0.02
	SWM	Log HF	Errors (4 boxes)	-0.41	0.045

Table 6.4 shows the results from Spearman's correlation performed between HRV (log RMSSD) and neurocognitive performance measures on the high and low HRV groups of the white-collar workers.

Key: AST = Attention Switching Task; HF = High frequency; HRV = Heart rate variability; LF/HF; Low frequency divided by high frequency; ms = Milliseconds; n = Sample size; p = Level of significance; r Correlation coefficient; RMSSD = Root mean squared of successive differences; RVP = Rapid visual processing task; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span task; TP = Total power; < = Less than

Log High Frequency

With a median of 5.07 (ms^2), the high log HF group (Table 6.5) indicated a positive relationship between log SDNN and congruent errors in the AST ($r = 0.42$, $p = 0.045$), and log LF/HF and errors made in the 6-box trial during the SWM task ($r = 0.47$, $p = 0.02$). The high log HF group also identified negative associations between log LF/HF and reaction time on correct trials during the AST ($r = -0.63$, $p < 0.01$), and between log LF/HF and errors on the 6-box trial of the SWM task ($r = -0.47$, $p = 0.02$).

The low log HF group (Table 6.5) showed a positive association between log SDNN and the total correct entries during the AST ($r = 0.43$, $p = 0.04$). Negative associations were identified during the AST between log LF and the total correct entries ($r =-0.44$, $p =0.03$), log HF and congruent errors ($r = -0.41$, $p =0.046$), log HF and reaction time when the “direction” cue was given ($r = -0.41$, $p = 0.049$), and log TP and total incorrect entries ($r = 0.46$, $p = 0.03$). A negative association was also found between log RMSSD and the errors made where a box was not shown in the sequence during the SSP task ($r = -0.42$, $p = 0.04$).

Table 6.5 Spearman's Correlation between HRV and Neurocognitive Performance Measures in the High and Low Log HF Groups (White-collar Workers)

Log HF Median = 5.07 (ms^2)	Task	Dependent Variable	Independent Variable	r	p
High n = 24	AST	Log SDNN	Errors (congruent)	0.41	0.049
		Log LF/HF	Reaction Time (correct)	-0.63	0.001
	SWM	Log HF	Errors (6 boxes)	-0.47	0.02
		Log LF/HF	Errors (6 boxes)	0.47	0.02
Low n = 24	AST	Log SDNN	Total Correct	0.43	0.04
		Log LF	Total Incorrect	-0.44	0.03
		Log HF	Congruent Errors	-0.41	0.046
			Reaction Time (direction)	-0.41	0.049
		Log TP	Total Incorrect	-0.46	0.03
	SSP	Log RMSSD	Errors (not in sequence)	-0.42	0.04

Table 6.5 shows the results from Spearman's correlation performed between HRV (log HF) and neurocognitive performance measures of the high and low HRV sub-groups of the white-collar workers.

Key: AST = Attention Switching Task; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Low frequency divided by high frequency; n = Sample size; p = Level of significance; r Correlation coefficient; RMSSD = Root mean squared of successive differences; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span task; SWM = Spatial working memory task; TP = Total power

Log LF/HF Ratio

With a median of 4.45, the high log LF/HF group (Table 6.6) demonstrated a negative correlation during the SSP task between log RMSSD and errors where the box was not next in the sequence ($r = -0.48$, $p = 0.02$).

The low log LF/HF group (Table 6.6) identified positive associations during the AST between log LF and reaction time when the “direction” cue was given ($r = 0.49$, $p = 0.01$), and log TP and reaction time when the “direction” cue was given ($r = 0.41$, $p = 0.049$). Additionally, positive relationships were found during the RVP task between log SDNN and reaction time of correct trials ($r = 0.42$, $p = 0.04$), log HF and reaction time during correct trials ($r = 0.51$, $p = 0.01$), and during the SWM task between log LF/HF and errors in the 6-box trial ($r = 0.57$, $p < 0.01$). The low log LF/HF group also demonstrated negative relationships between log LF/HF and reaction time during correct trials ($r = -0.52$, $p = 0.01$). During the RVP task a negative association was found between log LF/HF and reaction time during the correct trials ($r = -0.77$, $p < 0.001$). Moreover, during the SWM task negative relationships found were between log HF and errors during the 6-box trial ($r = -0.55$, $p = 0.01$), and log TP and errors during the 6-box trial ($r = -0.44$, $p = 0.03$).

Table 6.6 Spearman's Correlation between HRV and Neurocognitive Performance Measures in the High and Low Log LF/HF Sub-Groups (White-collar Workers)

Log LF/HF Median = 1.49	**Task**	**Dependent Variable**	**Independent Variable**	**r**	**p**
High n = 24	SSP	Log RMSSD	Errors (not next in sequence)	-0.48	0.02
Low n = 24	AST	Log LF	Reaction Time (direction)	0.49	0.01
		Log LF/HF*	Reaction Time (correct)*	-0.52	0.009
		Log TP	Reaction Time (direction)	0.41	0.049
	RVP	Log SDNN	Reaction Time (correct)	0.42	0.04
		Log HF	Reaction Time (correct)	0.51	0.01
		Log LF/HF*	Reaction Time (correct)*	-0.77	<0.001
	SWM	Log HF	Errors (6 boxes)	-0.55	0.005
		Log LF/HF*	Errors 6 (boxes)*	0.57	0.003
		Log TP	Errors 6 (boxes)	-0.44	0.03

Table 6.6 shows the results from Spearman's correlation performed between HRV (Log LF/HF) and neurocognitive performance measures on the high and low HRV sub-groups within the white-collar workers.

Key: AST = Attention Switching Task; HF = High frequency; HRV = Heart rate variability; LF = Low frequency; LF/HF = Low frequency divided by high frequency; n = Sample size; p = Level of significance; r Correlation coefficient; RMSSD = Root mean squared of successive differences; RVP = Rapid visual processing; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span task; SWM = Spatial working memory task; TP = Total power; * = Variables used in multiple regression analysis; < = Less than

A subsequent multiple regression analysis was performed for dependent variable log LF/HF (Table 6.7) using the significant correlations identified (Table 6.6: reaction time for correct trials during the AST and RVP task, and errors made on the 6-box trial of SWM). It was found to be overall significant for the white-collar LF/HF HRV (F(3,20) = 6.81, p = 0.002) and together the independent variables explain 43% of the variance in LF/HF of the white-collar (low HRV) group. Reaction time for correct trials during the RVP task was the significant predictor (p = 0.008).

Table 6.7 Multiple Regression between Log LF/HF (White-collar low HRV group) and Neurocognitive Performance Measures (n = 24)

Low White-collar (n = 24)	R	R Square	Adjusted R Square	Std. Error of the Estimate	p
Log LF/HF	0.71	0.51	0.43	0.64	**0.002**
	B	**Std. Error**	**Beta**	**t**	**p**
(Constant)	4.13	1.24		3.34	**0.003**
Reaction Time (AST)	0.00	0.001	0.03	0.13	0.90
Reaction Time (RVP)	-0.009	0.003	-0.57	-2.94	0.008
Errors 6 (SWM)	0.11	0.08	0.28	1.45	0.16

Table 6.7 displays the results of the multiple regression performed between the log LF/HF of the low HRV group for white-collar workers with performance measures on the neurocognitive tasks: reaction time on correct trials (AST), reaction time for correct sequences (RVP), and errors made on the 6-box trial (SWM).

Key: AST: Attention switching task; B = Unstandardised regression coefficient; LF/HF = Low frequency divided by high frequency; n = Sample size; p = Level of significance; R = Correlation coefficient; RVP = Rapid visual processing; R square = Proportion of variance; SWM = Spatial working memory; Std. = Standard; t = t statistic

6.3 Results: Comparison of High HRV versus Low HRV in Blue-Collar Workers

As described in Section 6.1, median splits were again performed, however, for the blue-collar worker group in this instance. The median splits separated the blue-collar worker group into high and low HRV sub-groups based on RMSSD, HF, and LF/HF.

6.3.1 Differences in Neurocognitive Performance between the High and Low HRV (Blue-Collar Workers)

For the blue-collar workers, Mann-Whitney U tests were performed (Table 6.8) to identify any differences in neurocognitive performance between the high HRV and low HRV groups.

It was identified that the high RMSSD group made less errors in the SSP task than the low RMSSD group (7.88 ± 5.7, 11.3 ± 6.69, respectively). The high log RMSSD group were unable to detect as many sequences as compared to the low log RMSSD group in the RVP task (0.8 ± 0.08, 0.9 ± 0.07, respectively). The high RMSSD group detected less sequences (33.08 ± 12.26, 40.61 ± 9.79, respectively) but also missed more sequences than the low log RMSSD group in the RVP task (20.92 ± 12.26, 13.39 ± 9.79, respectively).

The high HF group showed less errors during the SSP task (8 ± 5.95, 11.29 ± 6.56, respectively). The same difference was found between the high log HF and low log HF (8 ± 5.95, 11.29 ± 6.56) groups.

The high LF/HF group indicated better ability to detect sequences as compared to the low LF/HF group in the RVP task (41.19 ± 9.62, 33.07 ± 12.03). The high LF/HF group also missed less sequences than the low LF/HF group in the RVP task (12.81 ± 9.62, 20.92 ± 12.03). The same relationship was found between the high and low log LF/HF groups for sequence detection (41.19 ± 9.62, 33.07 ± 12.03), and sequences missed (12.81 ± 9.62, 20.92 ± 12.03) during the RVP task.

Table 6.8 Mann-Whitney U Test Comparing Neurocognitive Performance between the High and Low HRV Sub-Groups of the Blue-collar Worker Group (n = 53)

HRV	Variable (unit)	U	Z	p	High HRV Mean ± SD	Low HRV Mean ± SD	Mean Difference (high-low)
RMSSD M = 18.65 (ms)	Total Errors (not next in sequence)	227	-2.17	0.03	7.88 ± 5.7	11.3 ± 6.69	-3.4
Log RMSSD M = 6.69 (ms)	Signal Detection	234	-2.07	0.04	0.8 ± 0.08	0.9 ± 0.07	-0.04
	Sequences Detected	238	-1.99	0.047	33.08 ± 12.26	40.61 ± 9.79	-7.53
	Sequences Missed	238	-1.99	0.047	20.92 ± 12.26	13.39 ± 9.79	7.53
HF M = 101.72 (ms^2)	Total Errors (not next in sequence)	238	-2.0	0.046	8 ± 5.95	11.29 ± 6.56	-3.29
Log HF M = 4.62 (ms^2)	Total Errors (not next in sequence)	238	-2.0	0.046	8 ± 5.95	11.29 ± 6.56	-3.29
LF/HF M = 6.22	Sequences Detected	226	-2.24	0.03	41.19 ± 9.62	33.07 ± 12.03	8.12
	Sequences Missed	226	-2.24	0.03	12.81 ± 9.62	20.92 ± 12.03	-8.12
Log LF/HF M = 1.83	Sequences Detected	225	-2.24	0.03	41.19 ± 9.62	33.07 ± 12.03	8.12
	Sequences Missed	225	-2.24	0.03	12.81 ± 9.62	20.92 ± 12.03	-8.12

Table 6.8 shows the results of Mann-Whitney U tests performed on the high and low HRV sub-groups of the blue-collar worker group. Median split was performed between RMSSD, HF, and LF/HF as well as their log transformed counterparts. The parameters that showed significant differences ($p < 0.05$) were RMSSD, log RMSSD, HF, log HF, LF/HF, and log LF/HF.

Key: HF = High frequency; HRV = Heart rate variability; LF/HF = Low frequency divided by high frequency; M = Median; ms = Milliseconds; ms^2 = Milliseconds squared; n = Sample size; p = Level of significance; RMSSD = Root mean squared of successive differences; SD = Standard deviation; U = U test statistic; Z = Z score

6.3.2 Correlations between HRV and Neurocognitive Performance Measures in the High and Low HRV (Blue-Collar Workers)

As described in Section 6.2.2, the same analysis process used for the white-collar worker group was used for the blue-collar worker group (Section 6.3.2). Spearman's bivariate analyses were performed between the high and low HRV groups (log RMSSD, log HF, log LF/HF) and neurocognitive performance (Table 6.9, 6.10, and 6.11).

Log RMSSD

The high log RMSSD group (Table 6.9) identified positive associations during the SSP task between log SDNN and the longest sequence measured (r = 0.49, p = 0.001), and log LF/HF and errors where the box was not in the sequence at all (r = 0.39, p = 0.04). Positive associations were also found during the SWM task between log HF and the longest sequence measured (r = 0.57, p = 0.002). Moreover, during the SSP task, negative associations were also identified between log RMSSD and the longest sequence measured (r = -0.4, p = 0.04), log SDNN errors that did not appear next in the sequence (r = -0.38, p = 0.049), and between log LF/HF and the longest sequence measured (r = -0.51, p = 0.002).

The low log RMSSD group (Table 6.9) identified positive correlations during the RVP task between log RMSSD and errors where the box was not next in the sequence (r = 0.44, p = 0.03). Positive correlations were also identified during the SSP task between log SDNN and errors where the box was not next in the sequence (r = 0.44, p = 0.03), and between log TP and reaction time on correct trials (r = -0.43, p = 0.03). Negative associations in the low log RMSSD group were found during the SSP task between log TP and the longest sequence (r = -0.4, p = 0.045).

Table 6.9 Spearman's Correlations between HRV and Neurocognitive Performance Measures in High and Low Log RMSSD Sub-Groups (Blue-collar Workers)

Log RMSSD Median = 6.69 (ms)	Task	Dependent Variable	Independent Variable	r	p
High n = 24	SSP	Log RMSSD	Longest Sequence	-0.4	0.04
		Log SDNN	Longest Sequence	0.49	0.001
			Errors (not in sequence)	-0.38	0.049
		Log LF/HF	Longest Sequence	-0.51	0.01
			Errors (not in sequence)	0.39	0.04
	SWM	Log HF	Longest Sequence	0.57	0.002
Low n = 29	RVP	Log RMSSD	Errors (not next in sequence)	0.44	0.03
	SSP	Log SDNN	Errors (not next in sequence)	0.44	0.03
		Log TP	Reaction Time (correct)	0.43	0.03
			Longest Sequence	-0.4	0.045

Table 6.9 shows the results from Spearman's correlations performed between HRV (log RMSSD) and neurocognitive performance measures for the high and low HRV sub-groups of the blue-collar worker group.

Key: AST = Attention Switching Task; HF = High frequency; HRV = Heart rate variability; LF/HF; Low frequency divided by high frequency; ms = Milliseconds; n = Sample size; p = Level of significance; r Correlation coefficient; RMSSD = Root mean squared of successive differences; RVP = Rapid visual processing task; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span task; SWM = Spatial working memory task; TP = Total power

Log High Frequency

The high log HF group (Table 6.10) showed positive relationships during the RVP task between log SDNN, log HF, log TP, and reaction time during correct trials (r = 0.54, p = 0.003; r = 0.41, p = 0.03; r = 0.48, p = 0.01, respectively).

The low log HF group (Table 6.10) indicated positive correlations during the AST between log SDNN, log HF, and the total incorrect actions (r = 0.54, p = 0.01; r = 0.41, p = 0.04; respectively). Additionally, a positive correlation was also found during the RVP task between log LF/HF and the total sequences missed (r = 0.45, p = 0.02). Negative associations were observed during the RVP task between LF/HF and total sequences detected (r = -0.45, p = 0.02). During the SSP task, a negative correlation was found between log SDNN and errors where the box was not next in the sequence (r = -0.48, p = 0.03). And finally, a negative relationship was identified during the SWM task between log RMSSD and the use of strategy (r = -0.46, p = 0.02).

Table 6.10 Spearman's Correlations between HRV and Neurocognitive Performance Measures in the High and Low Log HF Sub-Groups (Blue-collar Workers)

Log HF Median = 4.62 (ms^2)	Task	Dependent Variable	Independent Variable	r	p
High n = 26	RVP	Log SDNN	Reaction Time (correct)	0.54	0.003
		Log HF	Reaction Time (correct)	0.41	0.03
		Log TP	Reaction Time (correct)	0.48	0.01
Low n = 27	AST	Log SDNN	Total Incorrect	0.54	0.01
		Log HF	Total Incorrect	0.41	0.04
	RVP	Log LF/HF	Total Sequences Detected	-0.45	0.02
			Total Sequences Missed	0.45	0.02
	SSP	Log SDNN	Errors (not in sequence)	-0.48	0.03
	SWM	Log RMSSD	Strategy	-0.46	0.02

Table 6.10 shows the results from Spearman's correlation performed between HRV (log HF) and neurocognitive performance measures on the high and low HRV sub-groups for the blue-collar worker group.

Key: AST = Attention Switching Task; HF = High frequency; HRV = Heart rate variability; LF/HF; Low frequency divided by high frequency; n = Sample size; p = Level of significance; r Correlation coefficient; RMSSD = Root mean squared of successive differences; RVP = Rapid visual processing task; SDNN = Standard deviation of all NN intervals (square root of variance); SSP = Spatial span task; SWM = Spatial working memory task; TP = Total power

Log LF/HF Ratio

In the high log LF/HF (Table 6.11) group, a negative correlation was observed between log RMSSD and strategy during the SWM task (r = -0.45, p = 0.02).

A positive correlation was identified in the low log LF/HF (Table 6.11) group between log TP and errors when the “side” que was given (r = 0.43, p = 0.03), during the AST. A negative association was also found during the AST between log LF and reaction times on incongruent trials (r = -0.68, p < 0.001).

Table 6.11 Spearman’s Correlations between HRV and Neurocognitive Performance Measures in the High and Low Log LF/HF Sub-Groups (Blue-collar Workers)

Log LF/HF **Median = 1.83**	**Task**	**Dependent Variable**	**Independent Variable**	**r**	**p**
High **n = 25**	SWM	Log RMSSD	Strategy	-0.45	0.02
Low **n =28**	AST	Log LF	Reaction Time (incongruent)	-0.68	<0.001
		Log TP	Errors (side)	0.43	0.03

Table 6.11 shows the results from Spearman’s correlation performed between HRV (log LF/HF) and neurocognitive performance measures on the high and low HRV sub-groups of the blue-collar workers.

Key: AST = Attention Switching Task; HRV = Heart rate variability; LF/HF; Low frequency divided by high frequency; n = Sample size; p = Level of significance; r Correlation coefficient; RMSSD = Root mean squared of successive differences; SWM = Spatial working memory task; TP = Total power; < = Less than

6.4 Discussion: High HRV versus Low HRV in White- and Blue-Collar Workers

This chapter provides a comparison of neurocognitive performance between the high HRV and low HRV groups within the blue- and white-collar worker groups. To address the fifth aim (Chapter 1.7) it was hypothesised that differences in neurocognitive performance would be observed between high HRV groups and low HRV groups within blue- and white-collar workers (Chapter 1.8, hypothesis 5).

Given the strong neurophysiological support and high correlation between RMSSD and its spectral correlate, high frequency (HF), the high HRV and low HRV groups were split around the median based on these parameters (RMSSD and HF HRV) (Malik et al., 1996, Thayer et al., 2000, Hansen et al., 2003, Thayer et al., 2009).

6.4.1 White-Collar Workers: Differences in Neurocognitive Performance between the High HRV and Low HRV Sub-Groups

The high RMSSD group showed better performance on the tasks; and was particularly linked to making less errors during the attention switching task (AST) and the spatial span (SSP) task. This is strongly supported by the literature which indicates that higher parasympathetic activity and increased vagal control (indexed by RMSSD) are associated with better performance (Colzato et al., 2018). Colzato and Steenbergen (2017) studied 88 healthy participants (average age = 21.2 ± 0.3 years, male = 50) investigating the relationship between vagally-mediated resting HRV (RMSSD) and executive function performance based on a stop-change paradigm (Steenbergen et al., 2015). It was observed that higher HRV participants demonstrated an enhanced ability to stop and change responses during executive function load (Colzato and Steenbergen, 2017), further supporting the notion that more vagal control of cardiac autonomic activity is associated with superior performance (Forte et al., 2019). In contrast to the literature, the present study found that the higher HF (HRV) group made more errors where typically, higher parasympathetic activity has been shown to be associated with better performance (Hansen et al., 2003). This may, consequently, highlight the characteristics of the task at hand playing a major role in moderating the relationship between HRV parameters and neurocognitive performance. A meta-analysis by Zahn et al. (2016) discussed this notion and indicated the importance of two executive control functions; the inhibition of unwanted responses and constant monitoring and updating of working memory. Both of these have shown a positive association with HRV (Zahn et al., 2016).

It is widely understood that higher parasympathetic activity, indexed by HRV parameters RMSSD and HF, is associated with better performance and, conversely, lower HRV parameters (RMSSD and HF) are associated with worse performance (Muthukrishnan et al., 2015). Additionally, it seems that both increased sympathetic activation and decreased parasympathetic activity are the main drivers for this interaction (Forte et al., 2019). Notwithstanding, the current findings may suggest that the classic assumptions of higher cardiac vagal control being associated with improved executive function does not hold universally (Duschek et al., 2009). Instead, it may be task dependant whereby, for example, the introduction of a time pressure may require additional cardiovascular adjustment to cope with the increased metabolic needs (Duschek et al., 2009).

6.4.2 White-Collar Workers: Neurocognitive Performance Correlations in the High HRV and Low HRV Sub-Groups

High RMMSD Group

There was a positive relationship between RMSSD and the number of errors, and a negative relationship between LF/HF HRV and reaction time, during the AST in the high HRV (RMSSD) group. This association between increased vagal tone and more errors is in contrast with the findings of the literature (Duschek et al., 2009, Forte et al., 2019), but as previously stated, it may further highlight the importance of task dependant influences on cardiac autonomic functions (Duschek et al., 2009). Moreover, supporting much of the literature, the increased parasympathetic dominance (LF/HF HRV) was associated with faster reaction times (Hansen et al., 2003, Forte et al., 2019). The high RMSSD group also showed numerous associations in the rapid visual processing (RVP) task. In a task of sustained attention (RVP), higher SDNN, LF, HF, and TP were all associated with longer reaction times. The general increase across multiple HRV indices is consistent with research regarding executive stimulation and load, which indicates that as executive function load increases autonomic HRV input also increases (Kimhy et al., 2013).

Low RMSSD Group

Interestingly, the low RMSSD group showed an inverse association between HRV measures, SDNN, HF, and TP, and reaction time. This indicates that as activity in these variables increased, the white-collar workers had faster reaction times. This is also consistent with the literature which indicates higher vagal tone is associated with better performance (Forte et al., 2019). However, an idea presented by Porges (1992) suggests that stronger autonomic reactivity (change between baseline and active) is found in individuals with higher resting cardiac vagal tone. Therefore, one may assume that this higher resting vagal tone allows for a stronger stress-induced change in performance (Duschek et al., 2009).

As noted, the high RMSSD group and the low RMSSD group showed inverse effects, particularly with reaction time. The literature indicates that varying baseline HRV may predispose an individual to a certain level of performance (i.e., higher HRV = better performance) (Forte et al., 2019). Alternatively, these results may further suggest that varying baseline HRV parameters may make an individual susceptible to reacting differently to certain stimuli and causing differing changes in cardiac autonomic input (i.e., someone with higher baseline HRV may react differently than someone with a lower baseline HRV) (Porges, 1992).

High HF Group

When data was split based on HF HRV, the high HF HRV white-collar workers showed an association between high parasympathetic activity (HF HRV) and reduced number of errors on the AST. Again, this is quite consistent across the literature indicating increased vagal control relates to better performance (Hansen et al., 2003). Additionally, the high HF HRV group exhibited a relationship between increased sympathetic dominance (LF/HF HRV) and faster reaction times during the AST. This may be due to increased mental stress and effort to perform well on the given task which, in turn, increases sympathetic dominance (Pagani et al., 1991). Moreover, during the spatial working memory (SWM) task, increased sympathetic activity was positively associated with errors and increased vagal control was inversely associated with errors, again supporting the findings of previous literature (Forte et al., 2019).

Low HF Group

During the AST, the white-collar workers that were classified into the low HF HRV group showed a positive association between overall HRV (SDNN HRV) and the number of correct responses. While, LF HRV had an inverse association with incorrect responses, indicating better performance. The present study also found an inverse relationship between parasympathetic cardiac activity (indexed by HF and RMSSD) and errors as well as reaction time. These results support previous findings which further highlights the critical role that vagal modulation plays in executive function (Scrimin et al., 2020). Total power (TP) HRV was also found to be inversely correlated to the total number of incorrect responses. Moreover, during the spatial span (SSP) task, increased cardiac vagal input (RMSSD HRV) was correlated with reduced errors, also consistently proven in the literature (Backs et al., 1994, Hansen et al., 2003, Muthukrishnan et al., 2015, Scrimin et al., 2020).

Cardiac vagal control and, its relationship to CVD and executive function performance, has been widely researched and is a stable characteristic of the parasympathetic influence on the electrical activity of the heart (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). At rest, higher vagal input appears to be a marker of both physiological and psychologically flexibility (Friedman and Thayer, 1998). This drives the importance of vagal control in being able to adaptively respond to the surrounding environment. However, the individual tasks that an individual performs on a daily basis may not be the only contributor to vagal dysregulation and CVD. Herr et al. (2015) examined the effect of organizational injustice on HRV. An assessment of 222 blue-collar (aged = 44.28 ± 9.91 years, male = 100%) and 179 white-collar (aged = 46.36 ± 8.70 years, male = 100%) workers confirmed the negative association between injustice and HRV for the white-collar group (Herr et al., 2015). This association, found only in the white-collar workers, is thought to be due to stronger direct social relationships with their employer

(DeConinck, 2010). This idea was initially indicated by Bies and Moag (1986), where an observation of interpersonal treatment and fairness shown by the supervisor had a robust association with HRV in white-collar workers. This suggests that measurements of the physiology alone may not illustrate an accurate image of the interactions between the brain and the heart. Therefore, despite the links between the prefrontal cortex and vagal mediation of cardiac activity being so strongly grounded in research (Porges, 2007, Thayer et al., 2009), organisational justice and perceived support may also indicate a strong impact on neurocognitive performance and HRV (Herr et al., 2015).

6.4.3 Blue-Collar Workers: Differences in Neurocognitive Performance between the High and Low HRV Sub-Groups

Differences between the high and low HRV sub-groups for the blue-collar workers showed somewhat contradictory results to that of previous literature (Hansen et al., 2003). Vagally mediated HRV is indexed by both RMSSD and HF HRV. These two HRV variables are observed to be highly correlated (Shaffer and Ginsberg, 2017), however, the current observations show some differing findings between HF and RMSSD HRV within the blue-collar workers. The blue-collar workers with high RMSSD indicated worse performance with a distinct difference in the ability to detect sequences during the RVP task. This poorer performance is contrasted by the high HF HRV group, which showed less errors made as compared to the low HF HRV group during the SSP task. Both HF HRV and RMSSD represent parasympathetic modulation, and as stated, both are correlated to one another. This unexpected relationship between RMSSD and HF HRV in the present study (i.e., no correlation between the two), was also found by Ravé et al. (2020). These authors assessed 14 soccer players from the French League (average age 27.9 ± 4.3 years, male = 100%) and showed that RMSSD was associated with perceived physical fitness and performance whilst HF HRV (normalised) showed an inverse association (Ravé et al., 2020). Notwithstanding, these two variables are strongly recognised to reflect vagal modulation and parasympathetic activity (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996) and the present study has found similar correlations between HF HRV and overall HRV markers (TP and SDNN) (Section 6.3.2, Table 6.9). This may suggest that HF HRV might primarily reflect total HRV whilst RMSSD may be a better marker of parasympathetic influence in blue-collar workers. Moreover, the differences presented here demonstrate the importance of assessing task dependant HRV parameters. It may not be sufficient to conclude on the effect of vagal control on performance in its entirety, particularly when many factors like neurophysiology (Porges, 2007, Thayer and Lane, 2009), diseased states (Massin et al., 1999), and metabolic demands (Duschek et al., 2009), among others, affect HRV and neurocognitive performance, which have been controlled for in the present study.

6.4.4 Blue-Collar: Neurocognitive Performance Correlations in the High and Low HRV Sub-Groups

High RMSSD and HF Group

The blue-collar workers showed various associations with HRV parameters, some of which were expected and others unexpected. Higher HRV had a positive correlation with vagal control (HF HRV) and the longest sequence remembered during the SSP task. This is expected given the results in the literature showing that higher vagal activity is associated with better performance (Forte et al., 2019). What was unexpected however, was the inverse relationship found between RMSSD HRV (parasympathetic activity) and the longest sequence remembered. Given that blue-collar workers often engage in activities involving spatial awareness, this finding suggests an element of memory adding to mental workload, which may have influenced these workers. Further to this notion, it was found that during the spatial working memory (SWM) task HF HRV was positively correlated with the number of errors made. This reinforces the idea that although the spatial awareness of blue-collar workers may be enhanced, the working memory element may be subject to increased mental workload and therefore, hindering their performance.

Low RMSSD and HF Group

The low RMSSD and low HF group also had poorer performance, particularly in a test of sustained attention (RVP). During the RVP task links between low RMSSD and low HF HRV were found with increased errors made, slower reaction times, and less sequences being detected. This is in support of the literature, which suggests that lower parasympathetic activity may predispose an individual to worse performance (Hansen et al., 2003, Forte et al., 2019). In a comparative study, Saus et al. (2006) investigated HRV and situational awareness in police officers (n = 40, average age = 24.88 between 22-30 years, female = 50%). These authors showed that the group that was trained in situational awareness not only performed better by a higher number of shots fired and greater accuracy, but also indicated high resting HRV was associated to individuals with better situational awareness (Saus et al., 2006). Moreover, Saus et al. (2006) study also supported the relationship that exists between cognitive demand and HRV such that HRV was found to decrease during performance, however, HRV was less reduced for the group that was previously trained for situational awareness. In support of this, a study of fighter pilots (n = 5, male = 100%, age not reported) showed that not only was there no difference in psychophysiology in a simulation task vs real life, but more importantly, HRV decreased as mental effort increased (Magnusson, 2002). Another study of a blue-collar profession, jockeys, demonstrated the importance of effort vs reward, as well as the effect of mental demand on HRV and performance execution (Landolt et al., 2017). Landolt et al. (2017) highlighted that in both high and low stress groups, decision making was impaired. Furthermore, the increased stress of work, as well as sympathetic dominance, negatively impacted cognitive performance and reaction time (Landolt et al., 2017). The results of the current study and previous literature continue to demonstrate the validity of vagally mediated cardiac influence on better performance, both psychologically and physiologically (Saus et al., 2006, Forte et al., 2019, Scrimin et al., 2020).

6.5 Conclusions: Comparison of High HRV and Low HRV Sub-Groups of the White-Collar and Blue-Collar Workers

The present findings of the blue- and white-collar workers identified a number of varying differences and associations. However, overall observations regarding cardiac vagal influence seem consistent with the literature, whereby higher RMSSD and HF were linked to better performance (Forte et al., 2019). In general, those with higher parasympathetic HRV (HF, RMSSD, and higher LF/HF) showed significantly better performance while the inverse was observed in those with lower parasympathetic HRV. Interestingly, the blue- and white-collar groups exhibited different correlations, and, in some cases showed the inverse relationship between the same variables. For example, the low HF group for white-collar workers showed that as total HRV increased so did the number of correct answers during the AST, while the low HF blue-collar workers groups showed increased incorrect answers as total HRV increased. This alludes to other factors, perhaps the influence of the workplace, on neurocognitive capabilities as well as the predisposition to cardiovascular disease (Duschek et al., 2009, Herr et al., 2015) .

A major notion discerned in the present study is that perhaps increased parasympathetic activity (or vagal modulation) may not simply signify better performance. Rather, it challenges this previous assumption such that the influences on individual HRV parameters may be task dependent, especially when highly correlated variables (HF HRV and RMSSD) show opposing associations.

Chapter 7 Conclusions and Future Directions

7.1 Limitations and Future Directions

The present research investigated the differences in, and relationships between, cardiac and neurocognitive variables in blue- and white-collar workers. While this study revealed some interesting and novel observations, there were some limitations, which will be discussed here and considered for future research.

The findings of the present study show that perhaps some of the changes in HRV may be a result of the individual tasks being performed, as these tasks may require different processes. If the sample size in each profession were increased more stratification could be performed allowing for observations of the effect of minor differences in tasks within the same type of job. For example, one white-collar worker might perform more administrative tasks while another may perform more data analytic type tasks despite having the same role.

Blood glucose level is another parameter which future studies may consider. This study did not restrict the intake of food, except for caffeine and alcohol, and given that glucose also influences HRV and cognitive performance, glucose levels should be assessed during the study. High mental demand requires increased mobilisation of glucose stores and therefore, is known to affect HRV and performance (Kennedy and Scholey, 2000, Singh et al., 2000). HRV was shown to be inversely associated with plasma glucose levels and HRV has been shown to be reduced in people with diabetes (Singh et al., 2000). Moreover, the high comorbidity of sleep apnea, causing hypoxia with diabetes, may further enhance the risk of cardiovascular mortality (Limberg et al., 2015) and therefore be taken into consideration when designing future studies.

Respiration is also known to affect HRV measures, especially as parasympathetic activity shifts into the lower HRV frequencies and inflates the frequency interval that defines sympathetic activity (Bernardi et al., 2000, Aysin and Aysin, 2006). If the respiration were to be manipulated during any part of the investigation, then the results may not truly reflect the processes occurring. It is therefore recommended that, as Laborde et al.

(2017) has mentioned, respiration rate should at least be measured to understand how it affects outcome measures, even if it is not controlled for.

Moreover, the cross-sectional design of the present exploratory study only provides a snapshot in time of the measures obtained. Physiological data is highly variable, and even though efforts were made to reduce variability (for example, using repeat measures to get averages, and using multiple assessments for working memory and attention), future studies could benefit from using 24-hour ambulatory ECG in a longitudinal design to obtain HRV parameters.

Though this study has identified multiple findings, it may only be predictive in nature and not necessarily causal. Therefore, future studies may also be able to investigate the causal link between vagal tone and these working memory and attention outcome measures through transcutaneous vagal nerve stimulation, a relatively new and non-invasive method of vagal nerve stimulation (Steenbergen et al., 2015). Recent research has identified that stimulation of the vagus nerve may be related to improved performance (McIntire et al., 2021). In addition, neuroimaging techniques may also help to identify if the brain processes differ between the blue- and white-collar workers in response to neural activation.

The findings of this research show ample corroboration with previous literature but also some conflicting results, whereby HF HRV and RMSSD HRV showed differing correlations (Forte et al., 2019). This therefore necessitates that future research consider the fundamental nature of the tasks, the different neurobiological aspects recruited to perform individual tasks, and the various consequences that might eventuate (i.e., different tasks might have different results not just a blanket relationship of low parasympathetic activity equals poor performance). It is therefore encouraged to assess these neurocognitive performance, and HRV, measures as a whole, as well as assessing the individual outcome measures.

On a note of additional interest, the recent COVID-19 pandemic, which occurred during the completion of this work, has proved detrimental to the workforce with job losses at their greatest in industries like accommodation, food services, and recreation services (Gilfillan, 2020). Additionally, full-time workers, casual workers, and men have been affected the most greatly affected (Gilfillan, 2020). Interestingly, with the literature surrounding COVID-19 growing, it has become evident that this recent pandemic has caused high stress environments within the workplace (Sriharan et al., 2021), revealed strong associations between financial strain and depressive symptoms (Hertz-Palmor et al., 2020), and increased psychological distress (Xiong et al., 2020). Therefore, links between pandemics such as COVID-19 and HRV and neurocognitive performance may be appealing to consider in future studies.

7.2 Conclusions: HRV and Neurocognitive Performance in Blue-Collar and White-Collar Workers

Corporate performance and workforce productivity is rapidly becoming the core focus of the 21st century in any industry or field. Not only does the workplace demand high levels of executive function and physical performance, but it also burdens people with immense psychological and physical pressure. With the Australian population approaching 26 million and an estimated GDP of $1.3 trillion in 2020 (Trading Economics, 2021), Australia's fast growing workforce requires attention and investigations concerning the health and neurocognitive performance that drives this growth. With the advent of the recent COVID-19 pandemic, high stress work environments, job losses, and stress have increased (Sriharan et al., 2021). The federal budget revealed an enormous $300 billion cost of COVID-19 to the Australian economy (The Commonwealth of Australia, 2021), thus providing strong grounds for future studies to consider COVID-19 and its links to neurocognitive performance and heart rate variability.

The literature has extensively investigated the effects of neurocognitive performance and cardiac modulation on cardiovascular disease (Angermann et al., 2012, Backe et al., 2012, Hillebrand et al., 2013, Kubota et al., 2017, Forte et al., 2019) and the prevailing opinion demonstrates low or reduced HRV (parasympathetic activity, or vagal modulation) predisposes to CVD and inferior neurocognitive performance. More recent research linking the decline in neurocognitive performance with CVD is increasingly growing (Angermann et al., 2012). However, the bulk of the literature assess global measures of cognitive performance without considering the minute, and sometimes immense, neurobiological effort required to perform the different tasks. Therefore, the present research has shed more light on the lacuna which exists regarding task-dependant variations in HRV and neurocognitive performance (specifically in areas of working memory and attention).

The findings of this research show ample corroboration of links between neurocognitive performance and HRV with previous literature. The blue- and the white-collar worker groups showed associations between reduced cardiac vagal input and poorer performance during the working memory and attention tasks. This is well supported by the literature (Duschek et al., 2009) as well as the link between mental stress and CVD

(Thayer et al., 2010), providing evidence that the adaptive nature of the cardiovascular system is dampened in response to mental load. The white-collar group also showed that as parasympathetic activity increased, performance of the tasks became significantly better. This was particularly seen in the reduction of errors, improved pattern recognition, and faster reaction times. The blue-collar workers identified a similar association between increased parasympathetic input and superior performance.

Apropos of HRV, the blue-collar workers showed reduced indices as compared to the white-collar worker group, primarily reduced parasympathetic modulation. The blue-collar occupation has identified many potential risk factors in developing CVD, including attenuated parasympathetic tone and baroreceptor activity in those who may sit more, as well as in other industries, such as accommodation, food services, and waste management, have all been implicated (Hillebrand et al., 2013, Voelker, 2014, Hallman et al., 2015). Ultimately, it was observed that the blue-collar workers had lower vagally mediated cardiac activity. Previous research has tried to conclude which profession is more at cardiac risk, but to no great avail. What we can infer, however, is the complicated dynamics that exist between the brain and the body during these cognitive tasks. Perhaps a judgement cannot be made on which profession is more predisposed to CVD, but more importantly, which tasks contribute to the detriment of cardiac autonomic modulation.

Moreover, the results of the blue- and white-collar workers identified many varying relationships to, and changes in, HRV. However, overall observations regarding cardiac vagal influence seem consistent with the literature. By and large, those with higher parasympathetic HRV showed significantly better performance while the inverse was observed in those with lower parasympathetic HRV. In any case, this suggests the significance of workplace influence on neurocognitive capabilities and CVD.

The foundation of this research rests upon the neurobiological pathways linking executive function to vagal control of the heart (i.e., polyvagal theory and the neurovisceral integration model) (Porges, 2007, Thayer et al., 2009). This has highlighted three major components of executive function; inhibition, working memory, and cognitive flexibility (shifting ability and attention) (Scrimin et al., 2020), all of which are assessed in the present research. Further, these executive functions play an important role in adapting and responding to continuously changing environments (Thayer et al., 2009). Therefore, the environment itself may have significant impacts on these neurocognitive processes (Scrimin et al., 2020).

Ultimately, a major notion described in the present study is that perhaps increased parasympathetic activity (or vagal modulation), as a whole, may not simply signify better performance. Rather, previous postulations could be challenged such that the cardiovascular and neurocognitive influences may be contextually task dependent.

The findings of this study will prove useful to corporations, organisations, and small business, as it provides markers for productivity, screening, and boosting employee performance. Moreover, the addition to cardiovascular research will help government bodies and policymakers to help reduce the overall burden of CVD on society. This study also guides future research into better understanding how neurocognitive performance may influence cardiac disease risk.

Chapter 8 Appendices

8.1 Consent Form

UNIVERSITY OF TECHNOLOGY, SYDNEY

CONSENT FORM

I ____________________ agree to participate in the research identified as '***Heart rate variability and neurocognitive performance: Investigating implications for cardiac risks in blue and white-collar workers'*** (Ethics approval no: UTS HREC REF NO. 2014000110), being conducted as part of a Doctor of Philosophy degree by Ardalan Eslami at the University of Technology Sydney, Building 4, Broadway. Funding for this research has been provided by the School of Life Sciences, Faculty of Science.

I understand that the purpose of this study is to investigate the relationship between cardiac autonomic activity, and memory and attention. I understand that this research will involve the use of an electrocardiogram (ECG) and various executive function tasks. I understand that there will be minimal risk and/or inconvenience.

I also understand the study will involve screening for blood pressure and the possibility that I may be found to have high blood pressure. If average blood pressure is greater than 140/90 mmHg I will be advised to consult a doctor. If average blood pressure is greater than 160/100 mmHg (moderate hypertension) (either systolic alone, diastolic alone or both) prior to the commencement of the study, I will not be included in the study and will be advised to consult my doctor or offered to be escorted to the nearest medical center by the researcher. If blood pressure measured after the study is greater than 160/100 mmHg, (either systolic alone, diastolic alone or both), I will be advised to consult my doctor or offered to be escorted to the nearest medical center by the researcher.

Ardalan Eslami has explained this study to me. I understand that my participation in this research will involve completing psychological and lifestyle questionnaires. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason.

I am aware that I can contact **Ardalan Eslami** on ph: or email: ardalan.eslami@student.uts.edu.au or the supervisor Associate Professor Sara Lal on (02) 9514 1592 or email: sara.lal@uts.edu.au if I have any concerns about the research. I agree that Ardalan Eslami has answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

____ ____/____/____

Signature (participant)

_______________________________________ ____/____/____

Signature (researcher or delegate)

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: 02 9514 9615, Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

8.2 Study Summary Sheet

Summary record of the research study

To be completed immediately after each study

Date: ________________

Name of researcher: ______________________________

Name of participant: ______________________________

1. Provide a brief summary of the study (tick one of the following):
   - the study went smoothly
   - there were some issues
   - there were major issues
2. Researchers general account and summary of the study- detail in a few lines or more:

____
____
____
____
____

3. Was there any 'out of the ordinary' event or issue in this study? Yes/No

If Yes, provide more details:

____
____
____
____
____

4. Was there an emergency situation? Yes/No

If Yes, provide more details:

____
____
____
____
____

Note:
If you answered Yes to Question 3, you must notify a senior researcher and/or responsible academic or deputy responsible academic immediately.
If you answered Yes to Question 4, (you SHOULD have followed the emergency protocol and you MUST report the incident using HIRO (Hazard and Incident reporting online) system via the UTS Safety and Wellbeing website: http://www.safetyandwellbeing.uts.edu.au/accidents/index.html
You must then notify a senior researcher and/or responsible academic or deputy responsible academic asap.

8.3 Neuroscience Research Unit Lifestyle Questionnaire (modified from the lifestyle appraisal questionnaire (Craig et al., 1996))

Directions: Please answer the following questions as accurately as possible. For some questions, you are required to tick the box that corresponds to your response.

1. Ethnicity ___________________

2. Place of birth (if not Australia) _____________________

3. What is your highest level of education? (tick and specify)
   □ Year 10 or equivalent
   □ Year 12 (HSC) or equivalent
   □ Diploma / TAFE qualification
   □ Bachelors degree
   □ Postgraduate study (e.g. Masters, Graduate Certificate, Postgraduate Medicine/Dentistry)
   □ Post Doctorate (PhD) or Higher
   Specify____

4. What is your current field?
   ____

5. Have you worked in another field/s? (Please specify)
   ____

6. Current relationship status?
   □ Single
   □ Married/Committed Relationship
   □ Divorced/Separated
   □ Widowed

7. Current smoking status? □ **Smoker** □ **Non-smoker**
   If you currently smoke, please specify how often?
   □ Socially (once a week or less)
   □ Daily (less than 10 cigarettes a day)
   □ Daily (10 cigarettes a day or more)
   □ Other (please specify __________________)

8. Have you ever been a regular smoker? □ **YES** □ **NO**

Neuroscience Research Unit Questionnaire Cont.

9. Have you ever tried to quit smoking? □ **YES** □ **NO**

10. Do you drink alcohol? □ **YES** □ **NO**
    If yes, how many standard drinks do you consume in a week? ____________
    Other (please specify ______________________________)

11. Do you drink caffeinated drinks? □ **YES** □ **NO**
    (e.g. tea, coffee, energy drinks)
    If yes, how many cups do you consume in a day? _____________

12. Do you currently have any chronic diseases/illness? □ **YES** □ **NO**
    If yes, please specify? ____

13. Do you have a family history of

Heart disease	□ **YES**	□ **NO**	Diabetes	□ **YES**	□ **NO**
Cancer	□ **YES**	□ **NO**	High blood pressure	□ **YES**	□ **NO**
Psychosis	□ **YES**	□ **NO**			

14. Do you currently take any drugs or medications? □ **YES** □ **NO**
    (e.g. pain killers, sleeping tablets etc.)
    If yes, please specify what you take, the reason for taking the medication, and how often?
    ____
    ____

15. Do you currently exercise? □ **YES** □ **NO**
    If yes, please specify how often
    □ Daily
    □ Weekly
    □ Every few weeks
    □ Every few months
    □ Other (please specify ____________________________)

16. Do you ever have any physical issues? □ **YES** □ **NO**
    (e.g. headaches, backaches, loss of appetite, sleep disturbance etc.)
    If yes, please specify?

____

Neuroscience Research Unit Questionnaire Cont.

17. Have you faced any majorly stressful events over the past year? □ **YES** □ **NO**
    (e.g. divorce, financial worries, illness, death of a loved one, job loss, etc.)
    If yes, please number how many _______________________

18. How often do you do activities you enjoy or that help you relax?
    (e.g. reading, sports etc.)
    □ Daily
    □ Weekly
    □ Monthly
    □ Rarely
    □ Never

19. How often do you get a good night's sleep?
    □ Most nights
    □ Every few nights
    □ Rarely
    □ Never

20. How many hours of sleep do you get a night? ____________________

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