# Effects of Caffeine on Cognitive Tasks

A thesis submitted in fulfilment of the requirements

for the degree of Master of Engineering

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# Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; and, any editorial work, paid or unpaid, carried out by a third party is acknowledged.

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**Lorraine Valladares**

February 2009

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And last but not least I dedicate this thesis to my mother **Rose Lena D'souza**, (still strong at 82), whom I most admire for bringing us up on one salary and never complaining about the tough times. **This is for You!**

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# Glossary

| | |
|---|---|
| AAN | American Academy of Neurology |
| ACC | Accuracy |
| BA | Broadmann Area |
| BA10 | Medial Frontopolar Cortex |
| CNS | Central Nervous System |
| DLPFC | Dorsolateral Prefrontal Cortex |
| EEG | Electroencephalogram |
| ERP | Event-related Potentials |
| fMRI | Functional Magnetic Resonance Imaging |
| MFG | Medial Frontal Gyrus |
| MRT | Mean response time |
| 'n' | Refers to a number which can take on the value of 1,2 or 3 |
| PET | Positron Emission Tomography |
| RACC | Right Anterior Cingulated Cortex |
| RDPC | Right Dorsolateral Prefrontal Cortex |
| RT | Reaction Time |
| SET | Stroop Executive Time |
| SRC | Stroop raw score SRC |
| WM | Working Memory |
| USARIEM | United States Army Research Institute of Environmental Medicine |

# Abstract

The effects of caffeine (250 mg) and placebo on healthy controls were studied in a double-blind, cross over study on 24 healthy subjects who performed a working memory n-back task. Reaction time and accuracy levels were tested using the n-back working memory measure in cognitive neuroscience. An experimental study tested on the 1, 2 and 3-back tasks under the placebo/coffee condition. Based on the empirical results obtained in this thesis it can be concluded that changes produced by caffeine ingestion support the hypothesis that caffeine acts as a stimulant. However, it cannot be proven that the stimulant translates into enhanced motor processes with an improvement in performance.

# Chapter 1

# INTRODUCTION

Numerous studies have examined the psychopharmacological and electrophysiological effects of caffeine on the human brain and heart (Bruce *et al.*, 1986). Caffeine has been tested to assess effects on sleep patterns, arousal, and its enhancement effectiveness of analgesics (Richardson *et al.*, 1995).

Drinking a cup of coffee is a daily pleasure for millions of people around the world. Widespread use of caffeine is of interest, in that it reflects the propensity of people who use caffeine as a stimulant drug (Benowitz, 1990). Average individual consumption is around three cups of coffee a day. Caffeine has been found to enhance mental performance, mood, and vigilance (Barry *et al.,* 2005). Research findings also present a great body of evidence on the medical aspects of caffeine enhancement on patients suffering from bi-polar disorder, schizophrenia, and depression (Coffey *et al.*,

1990; Callicott and Ramsey, 1998; and Callicott *et al.*, 2003).

However, there is comparatively little literature available on the effects of caffeine on healthy subjects with no medical impediments. Hence, this research proposed to answer the following question: Can a certain dosage of caffeine ingestion measurably enhance cognitive functions? Few studies have examined the effects of caffeine on cognition on **healthy** individuals.

A recent study challenged the observed beneficial effects on learning memory and performance (Koppelstaetter *et al.*, 2008). The Koppelstaetter study assessed the effect of caffeine on functional Magnetic Resonance Imaging (fMRI) signals during a 2-back verbal working memory task. Subjects underwent two sessions and were tested with 100 mg of caffeine to investigate whether caffeine did modulate working memory processes. Whilst studies state that caffeine increases arousal and overcomes fatigue there are no suggestions that caffeine consumption enhances specific cognitive functions.

This thesis was proposed and implemented in order to determine possible links between ingestion of caffeine and improvement in a cognitive n-back task. The n-back task requires participants to decide whether a currently-presented stimulus matches one presented 'n' trials earlier.

This thesis develops on Koppelstaetter study (Koppelstaetter *et al.*, 2008) which allows a fresh, feasible and practical approach for viewing caffeine and its effects on

human cognition whilst performing working memory (WM) tasks. It also examines the effects of caffeine and its cognitive response accuracy, whilst performing the n-back working memory tasks on healthy individuals.

## 1.1 Thesis Overview

Chapter 1 will provide an insight into psychological effects of relevant research on caffeine. In this chapter, previous caffeine studies will be discussed and existing findings reviewed.

Chapter 2 will have a detailed appraisal of the current research on caffeine and the influence of WM. This chapter will explore the body of knowledge that is available on WM along with existing studies and the confounding variables (such as fatigue and/or age) that affect WM.

A significant portion of this research program concentrated on the n-back paradigm. Chapter 3 will analyse, determine, and explore n-back methodology in order to effectively test WM. The difficulties encountered, previous theories and reported results will be summarised and discussed.

Chapter 4 will detail the design and methodology of this caffeine study. The testing objectives, strategies involved, motives and the overall picture will be outlined. Specific aspects of the chosen design and experimentation, which contrast the previously reported implementations, will be described.

To complement the theory, design and implementation, Chapters 5 and 6 will expose any inconsistencies or flaws that may be apparent. These two chapters will also include the method and results from raw data collected in this study, which will be evaluated and analysed.

Chapter 7 will provide comparisons, outcomes, and conclusions obtained in this research work. On completion of the theory, design, testing and evaluation, a comprehensive conclusion will be drawn. The discussion will highlight successful results obtained and propose areas for research and development, which can be pursued in future studies on cognition.

## 1.2 Cognition

Cognition is termed as the ability to consciously carry out functions utilising the human brain and includes: comprehension, visual perception, construction (sentences for example), calculation, attention (information processing), memory, planning, and problem-solving (Warburton, 1995).

## 1.3 Caffeine

Caffeine is present in a number of dietary sources consumed worldwide, including tea, coffee, coca cola beverages, chocolate bars and soft drinks. The content of caffeine in these food items varies and caffeine consumption from all sources can be estimated to be around 70 to 76 mg/person/day (Gilbert, 1981 and Gilbert, 1984).

## 1.4 Working Memory

Working memory is a system for temporarily storing and managing the information required for carrying out complex cognitive tasks such as learning, reasoning, and comprehension. Working memory is involved in the selection, initiation, and termination of information-processing functions such as encoding, storing, and retrieving data (Baddeley and Hitch, 1974). For example, memory span, which involves recalling letters or numbers by keeping this information on-line for a short period, is considered a test of working WM (Baddeley, 2000).

## 1.5 n-Back Tasks

The n-back task requires a subject to respond to previously seen stimuli. Thereby, 'n' refers to an integer which could be either, 1, 2 or 3-back. These tasks respectively require tracking an item 1-, 2-, or 3-back in a sequentially-presented list. An alternative

definition would be a task in which a letter displayed on a monitor screen is matched with the letter displayed 'n' letters previously (discussed in Chapter 3). By increasing 'n', the load on working memory is increased (Isoardi, 1999).

Caffeine, working memory and the n-back tasks are the three main elements used in this thesis for testing cognitive tasks. The manner in which these three variables combine, react and work on cognition will be addressed in detail.

## 1.6 Problem Statement

This research focuses on the fact that caffeine produces mild psycho stimulant effects which are hypothesised to underlie its widespread use. Levels of caffeine as little as 30 mg are detectable, can alter self-reports of mood and alertness and can improve processing speed and vigilance (Lieberman *et al.*, 1987).

If caffeine is so potent, what are its implications on the human mind and body? How does it affect day-to-day living? Does drinking a small amount or copious amounts, assist, improve and enhance cognition? Over the years, research has been identifying and revealing caffeine's neural pathway and the effects on cognition. Through technological development and different techniques research has ascertained that caffeine doses found in commonly consumed beverages produces net beneficial mood and performance enhancing effects in light nondependent users (Childs and de Wit, 2006).

## 1.7 Aims

The aim of this research is to determine whether caffeine enhances cognition in healthy subjects. Prior to this research work healthy subjects have not been assessed in sufficient detail. To this end it assesses (i) the effect of 250 mg of caffeine on response time (RT) and (ii) accuracy in normal healthy human controls.

By testing these factors, new information will be added to the current body of knowledge in this field. The outcome of this research may also respond to the interest in the community, with regards to the consumption of coffee. It is known that just one major industry player in Australia buys and roasts approximately 1,564 tons of coffee annually. Imagine the economic impact if research could prove beyond all reasonable doubt that caffeine enhanced intelligence and cognitive abilities!

## 1.8 Publications

The following work has been submitted for publication as a conference proceeding:

L. Valladares, I. Cosic, A. Bedford, and R. Croft, "Effects of Caffeine on Cognitive Tasks," CogSci 2009, July 30 to August 01, 2009, Amsterdam.

# Chapter 2

# CAFFEINE

Caffeine is widely consumed throughout the world for a variety of reasons, including its stimulant-like effects on mood and cognitive performance (Fredholm *et al.*, 1999 and Liberman *et al.*, 1987). The purpose of this study was to investigate the possible effect of **caffeine** on cognitive neural function in healthy human volunteers. Concentration of caffeine in coffee depends on the particular bean and how the beverage is prepared. So popular is caffeine usage that there are over 850 papers in the last ten years, on caffeine relating to smoking, illness, brain disorders, disability, exercise, alcohol and general usage.

## 2.1 Caffeine Pharmacokinetics

Caffeine absorption from the gastrointestinal tract is rapid and reaches 99% in humans in about 45 minutes after ingestion (Marks and Kelly, 1973). Peak plasma caffeine concentration is reached between 15 and 120 minutes (mins) after oral dosage, and therefore, it can be estimated that peak concentration is reached after 30 mins of ingestion. The hydrophobic properties of caffeine allow its passage through the biological membranes (Lachance *et al.*, 1983). Caffeine is an adenosine antagonist, which is a metabolism by-product and is an important regulator of sleep. The ability of caffeine to increase wakefulness is an important reason why people consume caffeine containing beverages.

It would be outside the scope of the present study, to cover all aspects of caffeine action in the central nervous system (CNS) (Daly, 1993 and Nehlig, 1992). However, we do know that the effects of caffeine on mood have been studied on human subjects and there is ample evidence that lower doses (20-200 mg) of caffeine are reliably associated with 'positive effects' (Griffiths and Mumford, 1995).

## 2.2 The Effect of Caffeine on Cognition

One effect of caffeine is the ability to manifests itself in lengthening the post firing duration in the hippocampus; this effect lasts longer than the changes induced by caffeing on the EEG (Kenemans and Lorist, 1995).

This study by Kenemans and Lorist has confirmed that caffeine increases the following:

(a) cortical activation
(b) the rate at which information about the stimulus accumulates
(c) selectivity particularly with regard to further processing of the primary attribution
(d) motor processes via central and peripheral mechanisms.

## 2.3 Caffeine and Mood

The effects of caffeine on mood have been widely studied in human subjects. Research has shown that lower doses (20-200 mg) of coffee are reliably associated with 'positive' subjective effects even in the absence of acute withdrawal effects (Griffiths *et al*, 1988). The subjects report that they feel energetic, imaginative, efficient, self-confident and alert; they feel able to concentrate and are motivated to work but also have the desire to socalise (Griffiths *et al.,* 1995). Functional Magnetic Resonance Imaging (fMRI) is used to study variations in mood by scanning hippocampal activity. The fMRI provides a basis for examining the location for the activity in the brain however it does not unambiguously determine the nature of the effect of caffeine on cognition (Fitzgerald *et al.,* 2008).

## 2.4 Other Caffeine Benefits

Caffeine ingestion is likely to produce small but significant gains in 5 km running performance for both well-trained and recreational runners (O'Rourke *et al.,* 2008). Caffeine has also been shown to have little analgesic effect when administered alone (Arai *et al*., 1990) but has been demonstrated in adults to enhance the analgesic effect of aspirin, acetaminophen and ibuprofen (Marks and Kelly, 1973) and (Morelli *et al*., 1994). Landolt in their research indicated that the presence of caffeine in the central nervous system during the waking episode reduces the progressive increase of sleep propensity associated with wakefulness (Landolt *et al.*, 1995).

## 2.5 Previous Studies on Cognition

A study on the effects of caffeine on the electrophysiological, cognitive and motor responses of the CNS analysed changes, by combining EEG, a word colour stroop test and Event-Related Potentials (ERP) (Ruijter *et al.*, 2000). Fifteen volunteers took 400 mg of caffeine/placebo in a randomised, crossover, double-blind design. The working memory task was a stroop colour test, naming colour and words printed in incongruent colours, i.e. naming the colour red, printed in green (incongruent word/colour presentation). Stroop raw score SRC and the Stroop Executive Time (SET) did not indicate significant changes in either parameter (Deslandes *et al.*, 2005). The design in this study was similar to using caffeine/placebo, in randomised crossover double-blind experimental design except for the fact that the dosage was 250 mg instead of 400 mg of caffeine and the working memory task was the n-back.

The research indicates that caffeine seemed to delay fatigue by blocking CNS adenosine receptors. In a study performed on rodents, it was shown that caffeine increased concentration; however, no significant results were reported in connection with humans (Conlay *et al*., 1997). The ability of humans to capture information from the environment is obviously a very complex process. Can caffeine have a measurable influence on cognition? Can intuitively suggestive performance decrement be due to boredom or fatigue?

In a statement from the American Academy of Neurology (AAN), it is assumed that "caffeine is a psychostimulant which appears to reduce cognitive decline in women". In this study involving 4197 women and 2820 men, no relationship could be established between caffeine intake and cognitive decline among men. However, the research has suggested that women may be more sensitive to the effects of caffeine and it is suggested that their bodies may react differently to the stimulant, as they may metabolize caffeine differently (Jeffery, 2007).

Childs and de Wit assigned 102 light caffeine users and tested whether the drug had any psychoactive or behavioural effects, with doses of 0, 150 and 450 mg (Child and de Wit, 2006). Caffeine (450 mg) significantly decreased the number of digits remembered in the backwards digit span task showing an impairment of working memory, caffeine did not affect digits remembered in the forward series; however, it increased the number of hits in the visual vigilance task. These findings suggest that at

higher doses, caffeine improved vigilance while impairing working memory. Consecutively, this study reduced the dosage to 250 mg, comparable with the average consumption of roughly 3 cups of coffee a day, with the aim of determining the effect of a restricted dose.

Kenemans and Lorist, likewise tested caffeine and visuo-spatial attention, with a smaller dosage of caffeine/placebo 1.5 and 3 mg/kg on 24 healthy human subjects (Kenemans and Lorist, 1995). Their study investigated the effects of caffeine in various tasks conditions to probe specific aspects of selective attention, based on the hypothesis that caffeine enhances selectivity of information processing. Their results indicated that caffeine mainly or exclusively affects processes related to the preparation and execution of the motor responses (Kenemans and Lorist, 1995). The present study will attempt to address this issue in relation to the n-back working memory task for enhancement in cognition.

A considerable body of research is available on the effects of caffeine. These studies have predominantly involved subjects with health issues. A cross section of examples reporting on the effects of caffeine on ailments, have been listed below:

(a) Caffeine and chronic low back pain (Currie *et al*., 1995)
(b) Caffeine and coronary heart disease (Cornelis and El-Sohemy, 2007)
(c) Caffeine and the kidney, what evidence right now? (Bolignano *et al.,* 2007)
(d) Caffeine a nutrient, a drug or a drug of abuse (Pardo *et al*., 2007)
(e) Caffeine consumption and the risk of type 2 diabetes and heart disease (Campos and Baylin, 2007)

(f) Coffee good, bad or just fun, a critical review of coffee's effects on liver enzymes (Homan and Mobarhan, 2006)

Physical performance and marksmanship during sustained operations especially with the Navy have promoted major research in caffeine. Defence scientists at the United States Army Research Institute of Environmental Medicine (USARIEM) have conducted a number of studies of caffeine in both rested and sleep-deprived volunteers. The intent of their work was to demonstrate that caffeine had militarily-relevant, beneficial effects on cognitive performance. For example, in non-sleep deprived military volunteers, their vigilance when attending to a radar-screen-like display for two hours was significantly improved following the ingestion of a moderate 200 mg dose of caffeine (Fine *et al.*, 1994). Their studies all confirmed that caffeine produced dose related improvements in visual vigilance, choice reaction time and repeated acquisition (a test of learning and memory). With military studies on caffeine, it was also reported that there are obvious adverse effects with caffeine consumption in high doses which increase anxiety and unsteadiness.

The US Army is promoting caffeinated gum to enhance physical and cognitive performance. Each stick of caffeinated gum contains 100 mg of caffeine, and the recommendation was one or two sticks every hour (McLellan *et al.*, 2004). To enhance the physical and cognitive challenges this study focused on the caffeine ingestion and tested with a dose of 250 mg, comparable to two sticks of caffeine used in the McLellan study, cited above.

By viewing Positron Emission Tomography (PET) in conjunction with fMRI images, a more complete picture of the cortical regions that participate in WM task can be painted. (Callicott *et al*., 1998). Recordings of primates have indicated that neural representation of information is associated with activation of widespread populations of association cortex neurons. However, the fMRI study testing caffeine confirmed increased response in the bilateral medial frontopolar cortex Broadmann Area (BA10), extending to the right anterior cingulated cortex (BA32) (Koppelstaetter *et al.*, 2008). Overall results show that common region mediates cognitive operations that are shared by different functions or sharing accounts (Cabeza *et al.*, 2002).

With progress being made in the medical field, many studies have tested caffeine through fMRI studies. These investigations have enabled the medical field to pin point neural activity by fMRI signal changes in a network of brain areas associated with executive and attentional functions during WM processes (Koppelstaetter *et al.*, 2008). Koppelstaetter *et al.* assigned 15 healthy right-handed males and assessed the effect of caffeine on the fMRI signal during a 2-back verbal WM task. All subjects were caffeine consumers, and underwent two scanning sessions separated by a 24-28 hour interval. Testing in the present study, also involved two sessions; however, the sessions included a 7-day "wash-out" period. Each participant received a dose of either placebo or caffeine, 20 mins prior to performing a working memory task in blinded crossover fashion. The only difference between this study and Koppelstaetter *et al.,* was that this study waited 30 mins prior to testing. With the fMRI scanning Koppelstaetter *et al.*, evidenced the neuronal activity and changes in a network of brain areas associated with

executive and attention functions during working memory processes. This thesis attempted to replicate and improve upon the findings of Koppelstaetter. By adding 1-back and 3-back and increasing the dosage to 250 mg instead of 200 mg could this study further illustrate that caffeine improves cognitive processes, whilst performing a WM task?

Koppelstaetter *et al.* (2008) concluded that the modulations seen in specific cortical regions suggest an effect on brain areas engaged in specific cognitive processes rather than a general effect due to the influence of caffeine on the vasculature. The most relevant aspect of Koppelstaetters' study was the confirmation that "caffeine had no significant effect on cognitive performance," which matched our experimental results and conclusions.

## 2.6 Summary

Deslandes tested subjects using 250 mg of caffeine. Caffeine had a stimulatory effect but there was no change in attention. Childs and de Wit indicated impairment with the high dosage of 450 mg of caffeine, however, the number of hits and digits recalled increased in vigilant tasks. Consequently, a question arises, could a different result be achieved or improved by reducing the dosage from 450 mg to 250 mg, which was tested with this study. Keneman tested caffeine by balancing dosage with weight and validated that caffeine enhanced information processing, similar to results in this study. Whilst the USARIEM study by McLlean *et al.,* 2004, tested 100. 200 and 300 mg doses in a double blind cross over design with placebo and caffeine and found

caffeine administered at 0300, 0500 and 0700- every two hours) were effective for maintaining cognitive function during a night of sleep deprivation. Koppelstaetter *et al*., 2008 reported stimulatory affects but no affects on cognition.

**Table 2.1:** Summary of studies carried out on the effects of caffeine on cognition.

| Study | Test | Effect |
|---|---|---|
| Deslandes *et al*., 2005 | Effects of caffeine on the electrophysiological, cognitive and motor responses of the (CNS) 250 mg of caffeine | Stimulatory effect however with no change in attention (Stroop test – naming colour and words) |
| Childs and de Wit 2006 | Tested whether the drug had any psychoactive or behavioural effects Tested with 150 and 450 mg | Decreased digits recalled and increased number of hits |
| Kenemans and Lorist 1995 | Caffeine and visuo-spatial attention 1.5/3 mg/weight | Caffeine shortened RT caffeine did not interact with the effect of task variables |
| United States Army Research Institute of Environmental Medicine (USARIEM), McLlean *et a.,* 2004 | Caffeine effects on cognition/sleep deprivation Dosage - 100, 200 and 300 mg of caffeine | Caffeine usage is acts as an intervention to enhance effectiveness during sustained operation and sleep deprivation |
| Koppelstaetter *et al*., 2008 | Effect of caffeine on fMRI signal during 2-back WM task. Subjects were all caffeine users (2 scanning sessions with only 100 mg of caffeine | "A" receptors affected by caffeine<br><br>No effect on cognition |

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# Chapter 3

# WORKING MEMORY

Working memory (WM) refers to a system which enables temporary storage and manipulations of information within the context of cognitive activity (Baddeley and Hitch, 1974). Baddeley and Hitch characterised WM as a type of mental workspace composed of 3 sub-systems:

- Central executive involved in control and selection process
- A buffer responsible for maintaining acoustically-coded information
- A buffer responsible for maintaining visual and spatial information.

Edward Smith defined WM as the cognitive mechanism that allows us to keep a limited amount of information active for a brief period of time (Smith *et al.*, 1996). Research indicates that there are different WMs associated with different kinds of information. WM is the ability to briefly retain and manipulate information in mind which is central to intelligent behaviour (McEvoy *et al.*, 1998).

The present study attempted to clarify whether WM is improved or enhanced in any way with ingestion of a controlled amount of caffeine. This study is a systematic attempt to address issues in relation to reaction time (RT) whilst performing a cognitive task. The fundamental characteristic of WM, are well known. Working memory capacity to handle information is limited; the physiological basis of this limitation has not been explained and is still being explored extensively.

Capacity limitation is usually reflected in cognitive testing, as decreasing performance in response to increasing working memory load (Miller, 1956 and Shallice, 1988).

Studies have shown that activation in dorsolateral prefrontal cortex DLPFC; Broadmann's area appears to be related to the active maintenance of information over decay (Cohen *et al.*, 1997 and Courtney *et al.*, 1996). In contrast, activation in areas such as the anterior cingulate is more the result of increased effort or task complexity (Pardo *et al.*, 2007 and Barch *et al.*, 2001). Whilst specific areas of the brain that are activated are of scientific interest, the focus in this study concentrated on whether or not caffeine enhanced cognition. The study did not dwell on the neurons that were activated. This nevertheless has been recorded and the EEG results will be used in further studies.

Gevins and Smith tested WM which is critical to high cognitive functions and the capacity to deliberately control attention in order to hold and manipulate information

(Gevins and Smith, 1996). Their results indicated that high-ability subjects made greater use of parietal regions and low-ability subjects relied exclusively on frontal regions.

There is still a need for further research on WM capacity and the present study attempted to replicate some of the work done by Baddeley (1992), by using the n–back paradigm for testing WM with the use of caffeine. It is a well established fact in science, regarding 'which' neurons are activated in the brain whilst performing cognitive tasks, however there is a paucity of research on the 'mechanisms' that drive the cognitive system. The cognitive, emotional and motivational control of WM is crucial, but largely ignored (Domasio, 2004). Domasio iterates that the multi component working memory model has a concept of information, but not equivalent to Freud's concept of mental energy.

Research in performance of everyday attentional failures happen, when attention to task is degraded through factors such as boredom, worry or dividing attention between several tasks simultaneously (Robertson *et al.*, 1997). Posner and Peterson defined sustained attention "as the ability to self-sustain mindful, conscious processing of stimuli whose repetitive, non-arousing qualities would otherwise lead to habituation as well as attention to other distracting stimuli" (Posner and Peterson, 1998). Would this study assist in examining the correlation between participants and conditions of coffee and placebo to assess what differences if any exist in regard to performance and response inhibitions?

Similar caffeine studies have tested the WM paradigm extensively using the n-back task with brain and trauma patients. Owen *et al.* conducted a quantitative meta-analysis of 668 sets of activation coordinates in 24 primary studies of n-back task variant manipulating process of WM (Owen *et al.*, 1997). Lavric *et al.* checked threat-evoked anxiety that disrupts spatial working memory performance (Lavric *et al.*, 2002). Studies have proven that nicotine influences cognition and behaviour and Ernst *et al.,* measured cognitive activation by using WM task (2-back task) in smokers (Ernst *et al.*, 2001). Overall, effects of nicotine and smoking on memory performance have been found to be weak.

This study scrutinises a similar paradigm; i.e., the n-back task by comparing the results achieved independently to validate whether any cognition enhancement in WM can be achieved with ingestion of caffeine/placebo.

# Chapter 4

# N-BACK TASKS

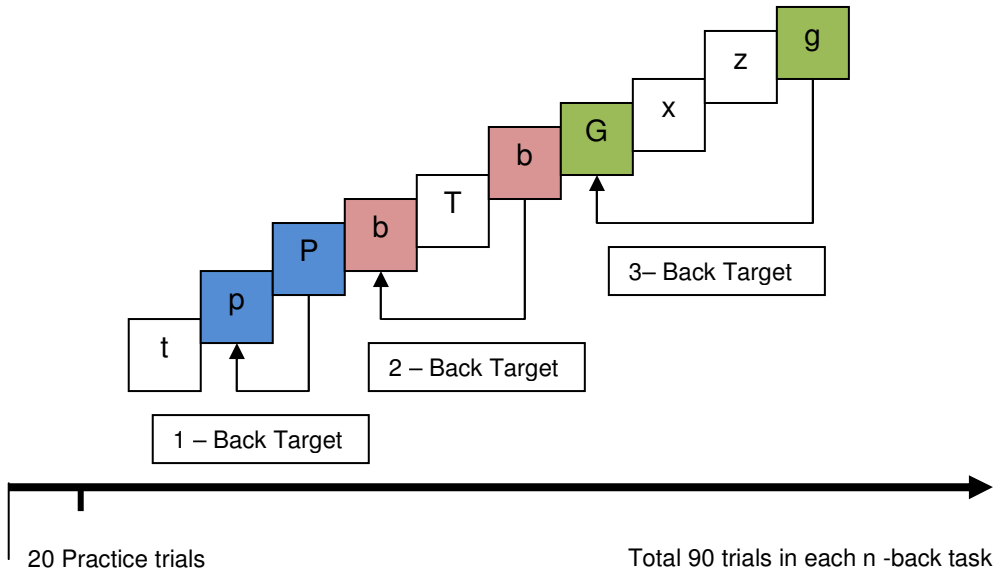


**Figure 4.1:** An example of a trial illustrating the schematic representation of the 3WM (n-back task). Each subject performed 20 practice trials, before performing 90 trials in the test, re-test sessions. The rationale for the occurrence of upper, and lower case respectively in the above diagram will be explained in Chapter 5.

This chapter starts by explaining the term n-back or the n-back task. The n-back is used to test WM. The task involves a number of stimuli that must be held in the mind at any one time, to be varied parametrically (Owen *et al.*, 2005). Figure 4.1 outlines a series of stimuli, in the present case letters, and participant had to match and identify the stimuli 1, 2, or 3 previously seen.

Invaluable information has been gathered through research on n-back paradigm. Previous experiments tested:

- Neural substrates
- Validity and test-retest validity of visuospatial WM
- Specific and non specific brain activity
- Electrophysiological index of WM
- The hemodynamic changes in brain patterns on patients with clinical and brain damage or impairments

Presently there has not been much focus on caffeine/the n-back on healthy individuals or generation Y that are the active forefront in the task force.

The n-back paradigm has been used in a variety of fMRI and PET studies to investigate the relationships between the organisation of brain activity and WM processing (Smith *et al.*, 1996; Braver *et al.*, 1997; and Cohen *et al.*, 1997).

## 4.1 Previous Studies

The n-back verbal task required participants to match responses of letter stimuli. Stimuli are presented sequentially and the subject must indicate whether the current stimulus is the same as the $n^{th}$ back item. This design was modelled after Jonides *et al.* utilisation of the parametric n-back task (Jonides *et al.*, 1997). Responses are made by pressing the "yes" button for target and 'no' for non-target.

Cerebral activity patterns were tested and studied by Jansma *et al.* to test the load sensitivity from fMRI data, whilst performing the 0-back, 1-back, 2-back, or 3-back task (Jansma *et al.*, 2000). Their aim was to separate the load sensitivity and concentrate on the increasing levels in cognitive task reaction times and to test enhancement in cognition. Findings indicated that good performance was correlated with a large area of load-sensitive activity in the anterior cingulate and with a small area of load-insensitive activity in the right parietal cortex.

Dosher and Ma found that memories will vary in strength or the probability of access depending on their time of acquisition among other factors (Dosher and Ma, 1998). Cohen *et al.* (2005) reported that the n-back task produces signification activation of Broca's area and the dorsolateral prefrontal cortex. Baddeley's WM model confirmed that increased activation in the posterior parietal region reflects the neural activity directed associated with increased storage demands (Baddeley, 1986). Voluminous amounts of data on neuron activity are available. The hemodynamic changes that occur during the time frame of the execution of cognitive task are well

recorded (Pochon et al, 2002). This thesis did not focus on the hemodynamics.

Geffen's research examined the cognitive basis of intelligence and suggested that mental intelligence is the product of faster speed of information processing; however, superior WM capacity is associated with greater accuracy of task performance scores (Hockey and Geffen, 2004). Hockey and Geffen tested performance on four levels of the n-back task (0-back, 1-back, 2-back, and 3-back), by testing over two sessions, and allowing a 1 week 'wash out' between sessions. The declining trend for accuracy of performance was predominantly linear across the four tasks, whilst reaction times increased exponentially.

McElree from New York University tested university students using 1, 2 and 3-back on WM and Focal Attention (McElree *et al.,* 2001). McElree ascertained that the amount of information that can be processed at one time is limited, and that in many cases, it is unlikely that all relevant by-products of recent processing can be actively maintained in the focus of attention. Experiments using the n-back task examined how much information could be maintained in focal attention while concurrently processing new information (Awh *et al.*, 1996; Cohen *et al.*, 1997; Dobbs and Rule, 1989, See and Ryan, 1995; and Smith *et al.,* 1998). The only difference with their study was McElree used a speed-accuracy trade-off procedure with three different kinds of experiments whilst our studies only concentrated on speed (RT) and accuracy (ACC).

McElree reported that substantial demands are placed on control (executive)

processes, because the response set must be continually updated as new items are encountered. For example, when a new item is presented, the former n-back item changes from a target to a distracter, the item that was formerly n-a back becomes the relevant target and all items less than n-back must be marked as future targets. This paradigm is useful for studying the interaction of various control memory processes (Smith and Jonides, 1997).

Consistent with McElree's findings it was noted that the retrieval process requires more time than matching, and that RT slowed markedly whenever retrieval is required. This means that measures of retrieval speed demonstrated that order information is retrieved by a comparatively slower search process when an item is not maintained within focal attention.

Pochon *et al.*, used fMRI to study brain activation in healthy subjects in the n-back paradigm, and manipulated the level of processing within WM and tested monetary reward associated with the performance of the task (Pochon *et al.*, 2002). WM load and mental manipulation within WM were incremented by using three levels of the n-back task (1, 2, and 3). Pochon *et al.* tested for neural architecture of WM and focused on the hemodynamic changes occurring during the time frame of the execution of the cognitive tasks and found that no significant activation associated with reward was detected in the neural areas. The authors concluded from their results that a balance between increasing activity in cortical cognitive areas, and decreasing activity in the limbic and paralimbic structures during ongoing higher cognitive processing.

Watter tested the n-back as a dual task, P300 morphology under divided attention, using the four levels of the n-back task (0-3) (Watter *et al.*, 2001). P300 (or P3b) component is a large distinct positive wave that peaks from 300 ms up to 800 ms or more. The amplitude is over the parietal modalities in the human brain. The tests used P300 latency and RT to investigate the effects of memory load, age, and other factors on stage of slowing information processing. Findings affirmed that P300 peak amplitude decreased progressively as WM load increased. These effects are interpreted as reflecting a reallocation of attention.

## 4.2 Summary

A summary of these studies is presented in Table 4.1. Jansma *et al.* fMRI study examined cerebral activity in response to graded demands on WM. Load sensitive signal change with increasing levels in cognitive task. This study provided a means to investigate cognitive deficits in psychiatry disorders. Hockey and Geffen tested under two conditions and from 0- to 3-back tasks to measure cognitive processes believed to underlie intelligence. This study attempted to determine whether caffeine enhanced intelligence. McElree validated that attention can only be allocated to a small number of memory representations. Pochon *et al.* fMRI study examined reward and recognition. Their results suggested a balance between increasing activity in cortical cognitive areas and decreasing activity in the limbic and paralimbic structures during ongoing higher cognitive processing. Watter tested P300 peak amplitude, which decreased with increased memory load.

**Table 4.1:** Summary of studies carried out on n-back memory tasks.

| Study | Test | Outcome |
|---|---|---|
| Jansma *et al.,* 2000 | Brain activity using n-back (0, 1, 2, and 3) Examined cerebral activity | WM processes co-localize and are presented in frontal and parietal regions |
| Hockey and Geffen, 2004 | Test, re-test reliability of WM task (four levels 0, 1, 2 and 3) | Intelligence is the product of faster speed of information processing |
| McElree, 2001 | WM and focal attention n-back (1, 2, and 3) Speed accuracy trade off | Attention can only be allocated to a small number of memory representations |
| Pochon *et al.,* 2002 | n-back tasks (1, 2, and 3) Neural activity and association with different levels of monetary rewards, fMRI scans | Areas were deactivated with the increase of cognitive demands. Areas activated by the reward value of the task had no effect on the level of cognitive processing |
| Watter *et al.,* 2001 | n-back as a dual task four levels (0-3) | Data supports a dual task nature of the n-back and additional cognitive demands |

# Chapter 5

# METHOD

## 5.1 Experimental Design

The current study comprised of 24 healthy volunteers aged between (19-38 years). Twelve males with a mean age of 26.5 years and 12 females with a mean age of 26.5 participated in this experiment. Participants were recruited from the University and surrounding community, via poster (attached in Appendix) advertisements and word-of-mouth referrals. Subjects were light/moderate caffeine users (i.e. they regularly consumed 2-4 cups of coffee or coca cola equivalents daily). Each participant had to qualify and meet the initial suitability criteria by answering a questionnaire (see Appendix). Participants had to be non-smokers. To be eligible, subjects were queried in detail about drug use, lactose tolerance, psychological/psychiatric disorders, medication or herbal supplements, blood pressure/heart problems, epilepsy, head injury, depression and hearing or visual impairments. In particular, subjects were queried about levels of depression and details of anxiety. All subjects gave written informed consent to take part in the study, which was approved by the Human Research Ethics Committee,

(Swinburne University of Technology, SUHERC 06/21 Effects of Caffeine on Brian Processing). The participants were compensated for their participation and time.

Cognitive psychology uses the Stanford Sleepiness Scale to test and assess the degree of alertness of an individual. This study used the Activation-Deactivation Adjective Check List (AD ACL) scale on 'The Biopsychology of Mood and Arousal' Thayer 1989. The AD ACL is a multidimensional test of various transitory arousal states, including energetic and tense arousal. This self-administered questionnaire is presented in Appendix 5. Although the information was collected and logged the statistics were not evaluated based on the hypothesis that caffeine enhances cognition.

### *5.1.1 Protocol*

Before the study began participants were given a two-page document outlining the investigators purpose and rationale of the project, possible hazards involved, time commitment, compensation for time and travel, privacy protection, discontinuation of participation, questions and a contact for complaints.

One day prior to testing, participants were reminded via email or telephone, about the following:

- No products containing caffeine (i.e. coffee, tea, coca cola, chocolate) were to be consumed after 11 am on testing days (4 hours prior to testing)

- No alcohol to be consumed for at least 24 hours prior to each testing session
- No illicit drugs to be consumed for at least 3 days prior to each testing session
- Participants completed NEO FFI (NEO Five-Factor Inventory) questionnaire. (Neuroticism and Openness to Experience).

Participants completed a short version of the NEO FFI (NEO Five-Factor Inventory) questionnaire that contained 60 items. The NEO FFI is a measure of the five major domains of personality as well as the six facets that define each domain. As part of psychological profiling the information about profile and personality traits are routinely gathered. However, in this study these results were not regarded of any significance, and therefore, were not evaluated. A copy of the NEO FFI is attached in Appendix 6.

## 5.2 Experimental Procedure

### *5.2.1 Equipment*

- Testing took place in the testing room at the Brain Science Institute (H99), Swinburne University of Technology. (Lighting was adjusted to dim)
- Computer desk with response key pad (consisting of a 'yes and no' button)

- Screen divider between the participant and Researcher
- Researcher's desk with STIM software (Neuroscan Inc. Sterling, VA, USA.

### *5.2.2 Study design*

A double blind, counter-balanced, placebo controlled, cross-over, repeated measures design was used. Each participant was tested under two different drug conditions [placebo or caffeine (250mg)] separated by a seven-day 'wash-out' period between two sessions.

The doses selected were based on previous research that found significant behavioural drug effects (Barry *et al.*, 2005), minimizing the possibility of side-effects, such as nausea, which could confound the study results. Upon arrival, participants were provided with a standard lunch consisting of four slices of toast with jam or vegemite and water to reduce the possible nausea caused by caffeine administration.

The timing of the testing sessions was kept constant through out the experiments. The testing of all participants in all sessions was conducted from 2:00 pm to 4:30 pm. Most people have two peak times of alertness during a day, at around 9:00 am and 9:00 pm. usually alertness wanes to its lowest point around 3:00 pm. This fact was accounted for in this study by testing all participants at 3:00 pm. It is a well known fact that people are less alert during the afternoon and hence 3:00 pm was chosen as a testing time. Each participant was administered 250 mg of caffeine in one hit. This

amount of caffeine was enough to enhance alertness when individuals are least alert. A further reason for choosing 3:00 pm was the availability of the laboratory for the experiments carried out in this study.

### *5.2.3 Caffeine dosage and administration*

Participants were given a flour-filled gelatin capsule, containing either caffeine or placebo, in a pre-determined randomized order immediately before the EEG calibration task and cognitive practice tasks. This allowed approximately 30 minutes before the testing, which coincides with the time that it takes for caffeine to reach its peak plasma concentration (Barry *et al.*, 2005, and Blanchard and Sawers, 1983).

### *5.2.4 Technique to reduce response bias*

Response bias can affect the results of statistical analysis. This is the case when respondents answer questions in the way they think the questioner wants them to answer rather than according to their true beliefs. Ordinarily this occurs when the questioner is aiming for a particular answer or if the respondent wishes to please the questioner by answering what appears to be the "morally right" answer.

In this study the following criteria were addressed in order to prevent Response Bias:

- the n-back task was designed to be clear, precise, and relatively short
- the n- back task for all participants was easy to interpret

- each participant answered the query in exactly the same way, after recognising and subsequently matching the stimuli the participant had to press the 'yes or no' button
- there was no ambiguity neither loaded or leading questions that could possibly confuse the participant.

The n-back assessment tests measured response time. Individuals were given the n-back task in a randomised fashion in order to eliminate individual subject bias. For example, Participant 1, performed the 2-back task first, followed by 1-back 1 and completed 3-back last (2, 1, and 3). Participant 2, performed the 3-back first, then 1-back and lastly 2-back (3, 1, and 2). There were 6 different combinations as follows: 1-2-3, 1-3-2, 2-1-3, 2-3-1, 3-1-2, 3-2-1. This technique enabled the minimisation of individual subject bias.

Cognitive intelligence is understood as the complex ability to think. It is the ability to solve new cognitive problems by thinking (without relying on pure recall of knowledge). In this study pure recall of knowledge would be highly unlikely given that there were 90 trials per n-back session. RTs were individually assessed to eliminate this bias and the raw data collected over two sessions for the three n-back tests (equivalent to 6 n-back tasks) is presented in the Appendix 3. Following the above criteria helped eliminate response bias.

### *5.2.5 Testing*

Testing required participants to be seated with their eyes at a distance of approximately 60 cm from the computer monitor screen. The lights were dimmed and they conducted a practice trial of the 1-, 2-, and 3-back to become familiar with these tests (details of the task have been described in greater detail below). Stimuli were delivered using STIM software (Neuroscan Inc. Sterling, VA, USA)

### *5.2.6 Cognitive experimental tasks*

N-back task was a stimuli, which in this study was a single white consonant presented for 500 ms each every 3s in the middle of a black computer screen (Koivisto, Krause *et al.*, 2000). The letter case was alternated at each appearance of each particular letter of the alphabet (e.g. z-b-Z-B). Letter case was treated as irrelevant, e.g., "g" and "G" were defined as matching. The rationale for alternating letter-case is to force participants to remember letters by their meaning rather than their shape (Levin et al., 2002). The 1, 2 and 3-back tasks were also administered in a counterbalanced order, so that the effects of memory load were not confounded by caffeine/placebo condition.

For example in the 1-back version of the task, participants were advised to indicate whether the stimuli matched the one shown immediately before it, (e.g. B-a-A) the second A would be a match. While in the 2-back version, participants must match the one shown two letters before (e.g. D-z-d) and D would be the target. Similarly in the 3-back (e.g. t-z-o-T) and the T would be the letter match shown 3 letters earlier. It is imperative to emphasise that the rationale for alternating letter-case is to force

participants to remember letters by their meaning rather than their shape (Levin *et al.*, 2002).

For each of the three n-back tasks (1-back, 2-back, and 3-back tasks), there were 90 stimuli (made up of 21 consonants, of which 30 were targets and 60 non-targets). (Koivisto, Krause *et al.*, 2000). The practice trail for each memory load consisted of 20 trials: 6 targets and 14 non-targets, in addition to the first n (non-target) stimuli (Koivisto, Krause *et al.*, 2000). Each stimulus was approximately 2cm wide and 4cm high on the screen, and was presented for 500 ms at the centre of a computer monitor, using Stim2 software and hardware (Version 4.0) (Neuroscan Inc. Sterling, Van, USA). Different versions were used for each level of difficulty and exposure condition.

A delay between n-back tests was provided as a rest period for subjects to relax after completing 90 trials, in order to allow the hemodynamics (blood flow – or feeling the pulse) to settle. This delay permitted the subjects to rest and recover from the previous task.

All letters not meeting these criteria were defined as "non-targets," including the first *n* stimuli which were non-targets by default, since an insufficient number of letters preceded them to make them targets). The practice trial or training trails for each memory load consisted of 20 + n stimuli: 6 targets and 14 non-targets, plus the first *n* (non-target) stimuli (Koivisto, Krause *et al.*, 2000).

Participants were asked to press 'Yes' as quickly and accurately as possible to each 'letter' that was the same as the letter 1, 2 or 3 stimuli perceived earlier (for the 1, 2 or 3-back task respectively), and otherwise to press 'No'. They were also instructed to ignore the case of the letters (which was varied to ensure that the intention rather than instantiation of the letters was used for memory).

# Chapter 6

# RESULTS

Mean reaction time and accuracy data were analysed by a two-way ANOVA testing the effects of 'groups' (A and B: Group A consisted of participants consuming placebo first and coffee in the second session. Group B involved participants who consumed coffee first and placebo in session two. The term 'drug' will refer to coffee or placebo. While the term 'tasks' refers to an n-back task, with 'n' standing for 1, 2, and 3).

## 6.1 Comparisons of Mean Response Time

In this section the treatment effects were evaluated. This measure assists in establishing potential differences in the data before performing ANOVA tests to account for in-variable interactions.

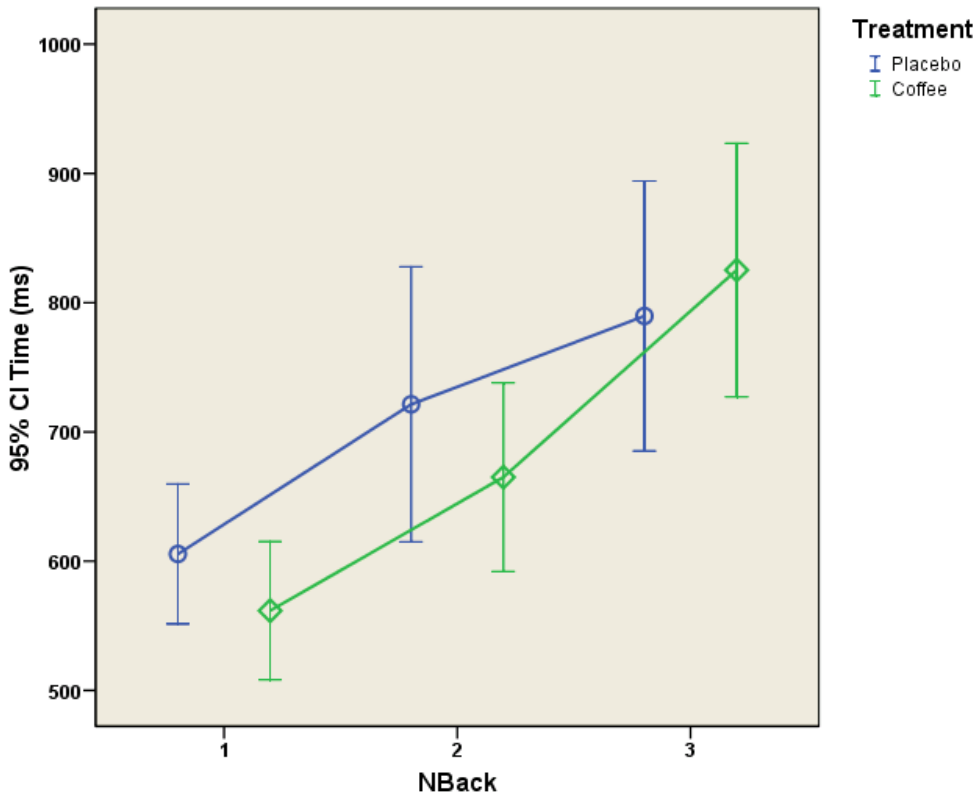


**Figure 6.1:** Behavioural data presented for visual comparison: 95 % Confidence Interval for the mean response time MRT for placebo and coffee ingestion, estimated by n-back: (1-, 2-, and 3-back). In this study 24 human subjects were investigated who participated in 2 sessions. Data was collapsed across the different treatment conditions (coffee or placebo for all 24 participants over 2 sessions = 48 experiments). The error bar range suggests that reaction time increased with working memory load.

The graph in Fig. 6.1 compares all subjects taking a placebo (irrespective of the groupings) to all subjects taking coffee. This provides an overall illustration of the three n-back tasks for the entire experiments, showing differences between all subjects that ingested placebo and coffee. Placebo takers had a higher mean response time (MRT) for n-back 1 and 2, whilst caffeine takers had a higher MRT for 3-back tasks. Groups ingesting coffee showed better performance. There was improvement in MRT in both 1 and 2-back tasks.

**Table 6.1:** The t-test assesses whether the means of two groups are *statistically* different from each other.

| Source | t-value | df (degrees of freedom) | p value |
|---|---|---|---|
| Coffee 1 to 2-back | 2.362 | 46 | .022 |
| Placebo 1 to 2-back | 2.007 | 46 | .051 |
| Coffee 2 to 3-back | 2.709 | 46 | .009 |
| Placebo 2 to 3-back | 0.949 | 46 | .348 |

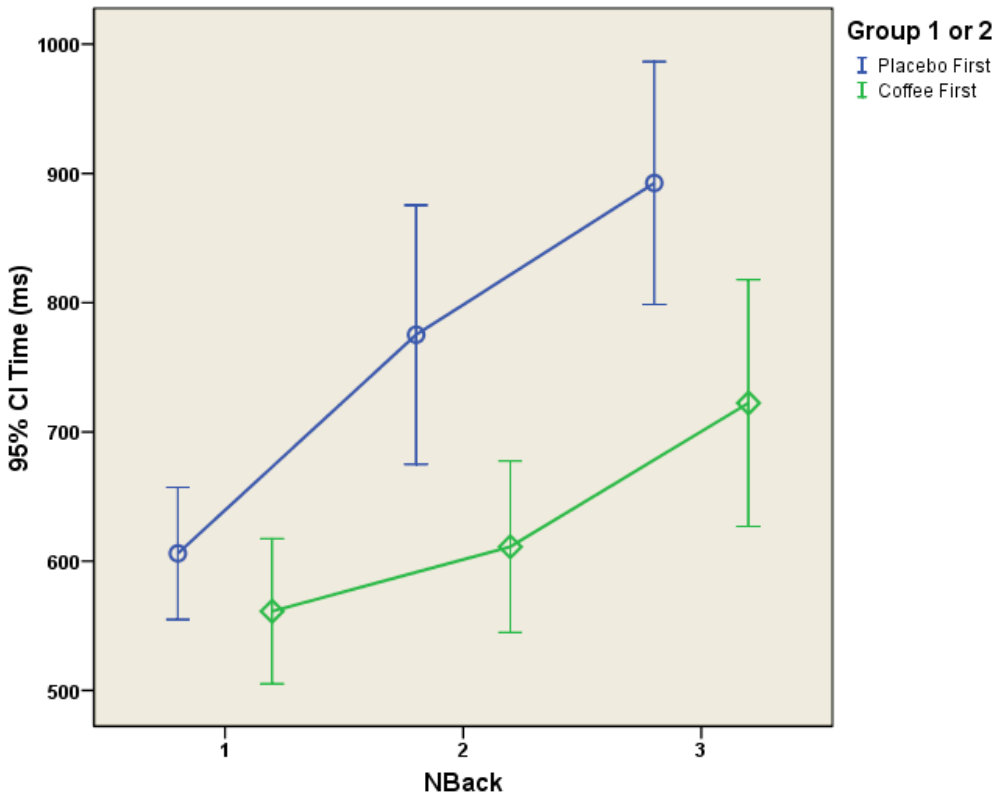


**Figure 6.2:** Percentage increase in reaction time. MRTs for all 3 trials: 95% confidence interval for MRT for coffee first vs. placebo first by n-back: 1-back, 2-back, and 3-back, across task conditions.

Figure 6.2 illustrates the MRT for caffeine/placebo. Participants taking coffee first (green bar) had a significantly lower MRT for all n-back experiments. This does not account for whether or not the group ingested coffee or placebo, Group A or B, rather provides the MRT of all their experiments. This indicates that being in the coffee first group significantly impacts MRT, irrespective of treatment.

**Table 6.2:** The t-test assesses whether the means of two groups are *statistically* different from each other.

| Targets | *t* value | *df* | *p* value |
|---|---|---|---|
| 1-back | 1.218 | 46 | .229 |
| 2-back | 2.824 | 46 | .007 |
| 3-back | 2.628 | 46 | .012 |

Figure 6.3 summarises the trend of the results obtained for Group A and B together in one graph. The participants in Group A were given a placebo sham in session 1(blue curve) and coffee in session 2 a week later (red curve). The participants in Group B were given coffee in session 1(green curve) and placebo in session 2 a week later (purple curve). Group A exhibited a markedly higher MRT compared to Group B. This weakness was identified in the previous figure (Fig. 6.2).

In Fig. 6.4, MRT gradually increased with WM load. 3-back proving the most difficult task, with the longest MRT. Retrieval decreased as n increased in all variants of the n-back task.

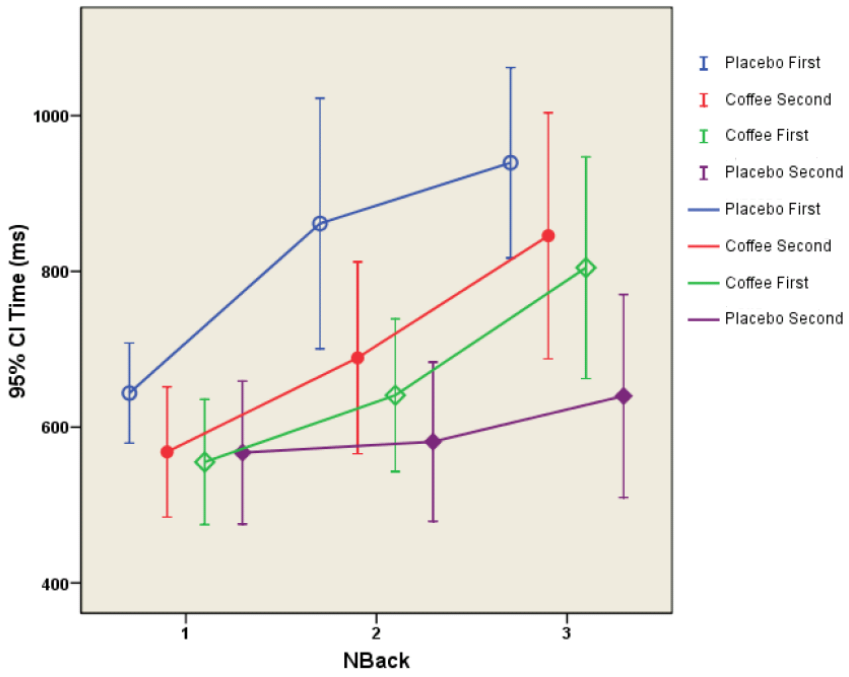


**Figure 6.3:** Activity data, MRT of performance across the n-back task**.** 95% confidence interval of the mean response time for all subjects (grouped) at each point of the experiment by n-back: 1-back, 2-back and 3-back. Data displayed within sessions and across task conditions and degrees of practice and then collapsed across treatment conditions. For all 4 sessions

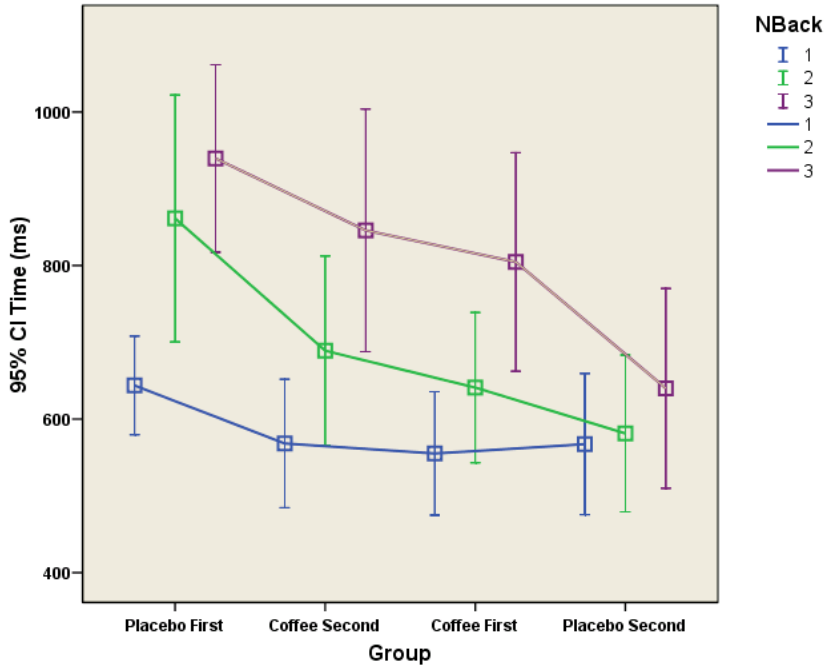


**Figure 6.4:** Behavioural data presented for visual comparison: 95% confidence interval of the mean response time for all subjects (grouped) by n-back: 1-back, 2-back, and 3-back. Data displayed across task conditions and collapsed across working memory task.

## 6.2 ANOVA Tests for Between-Subject Effects for MRT

ANOVA testing was conducted to determine any significant differences between RTs for the groups, n-backs, treatments, and their interactions. The data was split into the four groups (placebo first, coffee first, placebo second, coffee second), with all passing the Kolmogorov-Smirnov normality tests ($p > 0.05$), meeting one of the underlying assumptions of the ANOVA test. Posthoc analysis was conducted utilising Tukey's Honestly Significant Difference (HSD) test. Significant differences were found amongst all 3 n-back task comparisons (1 versus 2: $p<.012$, 1 versus 3: $p<.001$, 2 versus 3: $p<.01$).

**Table 6.3:** Test of between-subject effects. The dependent variable is time.

| Source | Type III Sum of Squares | *df* | Mean Square | *F* | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 2348011.793[a] | 11 | 213455.618 | 6.298 | .000 |
| Intercept | 69509477.410 | 1 | 69509477.410 | 2050.989 | .000 |
| n-Back | 1202855.113 | 2 | 601427.557 | 17.746 | .000 |
| Group 1 or 2 | 574683.110 | 1 | 574683.110 | 16.957 | .000 |
| Treatment | 16769.015 | 1 | 16769.015 | .495 | .483 |
| n-Back * Group 1 or 2 | 120098.259 | 2 | 60049.130 | 1.772 | .174 |
| n-Back * Treatment | 59548.654 | 2 | 29774.327 | .879 | .418 |
| Group 1 or 2 * Treatment | 306915.128 | 1 | 306915.128 | 9.056 | .003 |
| n-Back * Group 1 or 2 * Treatment | 67142.513 | 2 | 33571.257 | .991 | .374 |
| Error | 4473572.956 | 132 | 33890.704 | | |
| Total | 76331062.159 | 144 | | | |
| Corrected Total | 6821584.750 | 143 | | | |

[a] R-Squared = 0.344 (Adjusted R-Squared = 0.290)

## 6.3 Data Analysis

The two-way ANOVA between-subjects effects model was conducted in SPSS, yielding a variety of significances. The n-back $F(2,143)=17.746$, $p < .001$, and Group A or B $F(1,143)=16.957$, $p <.001$, were highly significant, leading to the conclusion the MRT are not equivalent for the differences type of tests, and for the two different groups (A or B). The Treatment (Coffee or Placebo) was not statistically significant (akin to that presented in Fig. 6.1), yielding $F(1,143) = .495$, $p = .483$. The interaction effects were also investigated, as error plots illustrated co-operative relationships between the variables. The Group (A or B) and Treatment (Coffee or Placebo) were statistically significant [$F(1,143) = 9.056$, $p = .003$], meaning that the type of treatment and group selection worked together to create difference in MRT, as seen in Fig. 6.1. The other second-level interaction effects n-back and Group; n-back and treatment, did not yield significance $F(2,143) = 1.772$, $p = .174$; $F(2,143) = .879$, $p = .418$. This indicates that the type of test (n-back 1, 2 or 3) did not work together with group or treatment to provide significantly different MRT. Finally, the third-level interaction was investigated, yielding $F(2,143) = .99$, $p = .374$, a non-significant result.

## 6.4 Visual Comparisons of Accuracy

There are accuracy variations of participants' responses to the stimuli, with accuracy estimated as the percentage of correct responses to the 90 n-back stimuli. It should be noted that no minimum accuracy level criterion was set for the study. Notably, 7 out of 84 (8.3%) of paired results showed a discrepancy of more than 10%.

Test sequencing was different each time (e.g., 3-2-1, or 2-1-3) and the letter order varied. Accuracy was gauged on respondents obtaining a record hit rate of 100% correct answers. In this study getting 90 trials correct corresponds to a 100% accuracy.

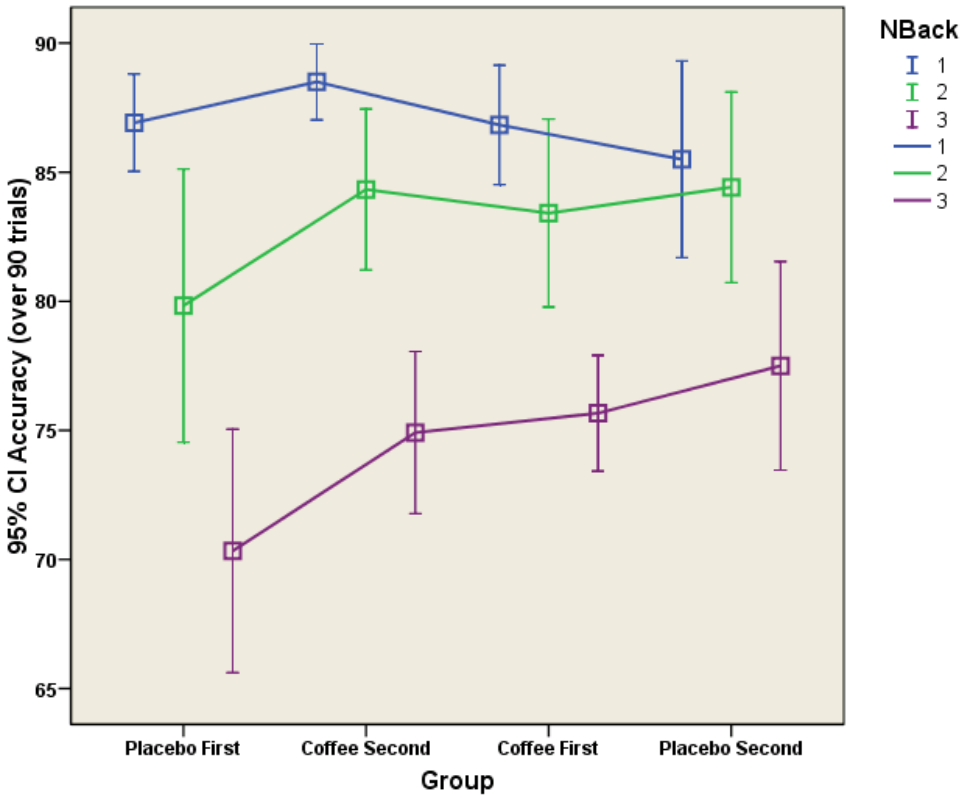


**Figure 6.5:** Average mean percentage accuracy levels of Group A and B (4 sessions) by n-back task. Accuracy Data for the three levels of task difficulty. 95% confidence interval of accuracy over 90 trials. This provides a pictorial image where the coffee second group performed better than coffee first.

As previously plotted n-back 1, has the highest level of accuracy. Figure 6.5 illustrates the mean percentage accuracy for each of the four sessions by n-back. The coffee second group had the highest mean accuracy for n-back 1, whereas the placebo second had the highest accuracy for n-back 2 and 3.

## 6.5 Visual Comparisons of Accuracy Levels on n-Back Tasks by Groups

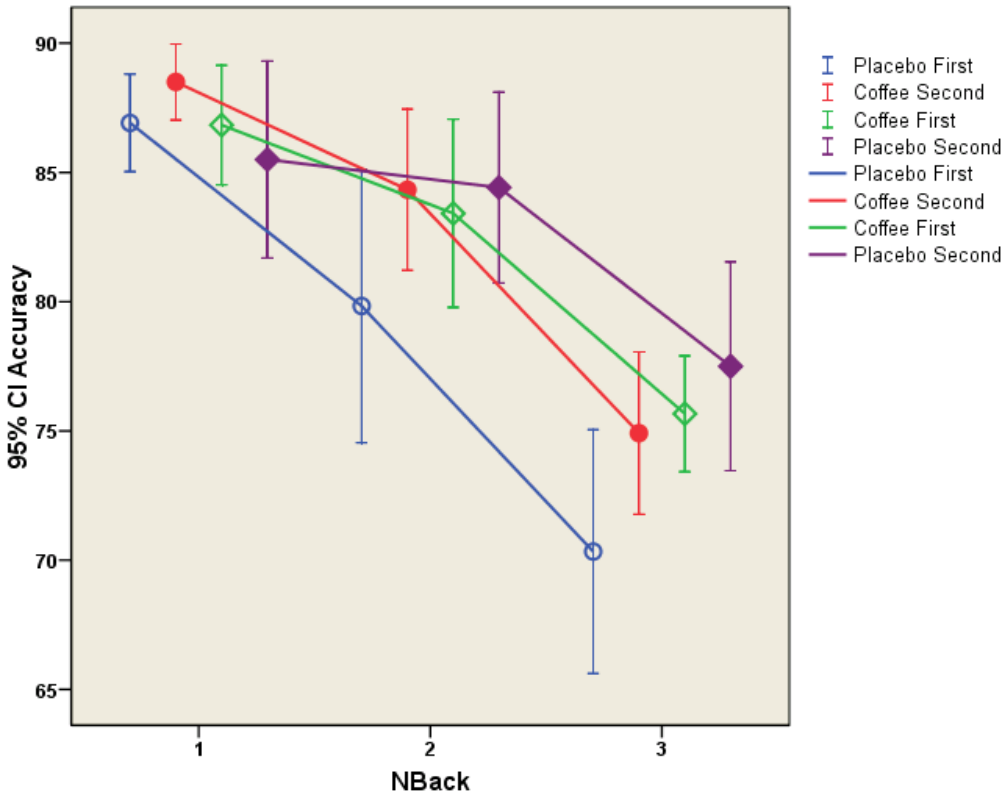


**Figure 6.6:** Plots the n-back by groups. Visual complexity of accuracy levels within the groups. 95% confidence interval depicting sessions 1 and 2 of groups A & B. Average accuracy for each of the groupings presented and the proportion of drop in accuracy levels whilst performing 3-back which had the greatest difficulty.

All participants found 3-back task difficult and accuracy levels dropped considerably. The participants in Group A were given a placebo sham in session 1(blue curve) and coffee in session 2 a week later (red curve). The participants in Group B were given coffee in session 1(green curve) and placebo in session 2 a week later (purple curve). Familiarity, learning and tiredness could have been factors that affected the results.

Accuracy analyses found significant results for n-back 1, with coffee ingestion, which provides further validation that caffeine does enhance mental alertness but does not converge into improvement in cognition. Posthoc analysis was conducted utilising Tukey's Honestly Significant Difference (HSD) test and showed that all relationships are significant.

**Table 6.4:** Test of between-subject effects. The dependent variable is time.

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | .539[a] | 11 | .049 | 13.386 | .000 |
| Intercept | 118.125 | 1 | 118.125 | 32268.504 | .000 |
| n-Back | .470 | 2 | .235 | 64.241 | .000 |
| Group 1 or 2 | .010 | 1 | .010 | 2.834 | .095 |
| Treatment | .009 | 1 | .009 | 2.437 | .121 |
| n-Back * Group 1 or 2 | .000 | 2 | 5.74E-5 | .016 | .984 |
| n-Back * Treatment | .023 | 2 | .011 | 3.113 | .048 |
| Group 1 or 2 * Treatment | .018 | 1 | .018 | 4.992 | .027 |
| n-Back * Group 1 or 2 * Treatment | .008 | 2 | .004 | 1.120 | .329 |
| Error | .483 | 132 | .004 | | |
| Total | 119.147 | 144 | | | |
| Corrected Total | 1.022 | 143 | | | |

[a] R-Squared = 0.527 (Adjusted R-Squared = 0.488)

An ANOVA was conducted on mean accuracy levels to determine if there was any significant difference between the groups. A full interaction model was utilised. The only significant difference occurred in relation to the 3-back $F(2, 143) = 64.241$, $p = .001$ indicating, as shown in the Fig. 6.6. Treatment (coffee or placebo) and Group (1

or 2) showed no significant differences in mean accuracy level $F(1,143) = 2.834$, $p = .095$; $F(1,143) = 2.437$, $p = .121$.

There was a significant interaction between n-back and group, with $F(2,143) = 3.113$, $p = .048$. This implies that the group selection works together with n-back. Similarly, Treatment and Group work together, even though they are not significant on their own $F(1,143) = 4.992$, $p = .027$. Consequently, which group and what was ingested influenced accuracy levels. The three way interaction effect produces a non-significant result $F(2,143) = 1.120$, $p = .329$.

## 6.6 Accuracy (Paired)

The analysis in the section considers the paired differences between participants in terms of their coffee/ placebo dose, irrespective of which one was administered first.

The group that had coffee second always performed better on each 1-back task. Mean reaction time and standard deviation table:

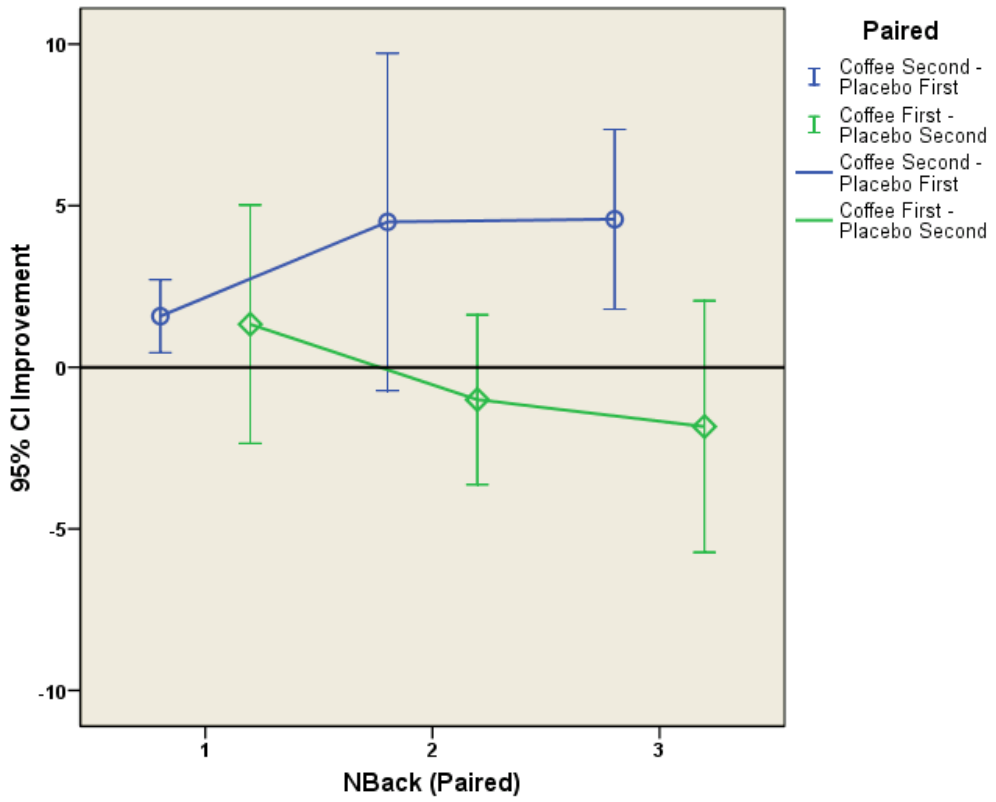


**Figure 6.7:** Accuracy paired the data is matched to determine if there is any decline or improvement in accuracy levels for the two groups: 95% confidence interval for accuracy across task conditions. The group that had coffee second always performed better on each 1-back task.

## 6.7 Accuracy Levels for Placebo/Coffee

Finally, an ANOVA was conducted on the paired data. Notably the n-back (paired) is not statistically significant, indicating that there is no difference in mean percentage improvement levels for the n-back tests, specifically the test difficulty had no impact of mean percentage improvement levels. $F(2,71) = 031$, $p = .969$. As expected, the order of pairing, that is, whether the subject had coffee first or second, was significant. $F(1,71) = 9.963$, $p = .002$. Finally the interaction term was not significant, $F(2,71) = 2.236$, $p = .115$.

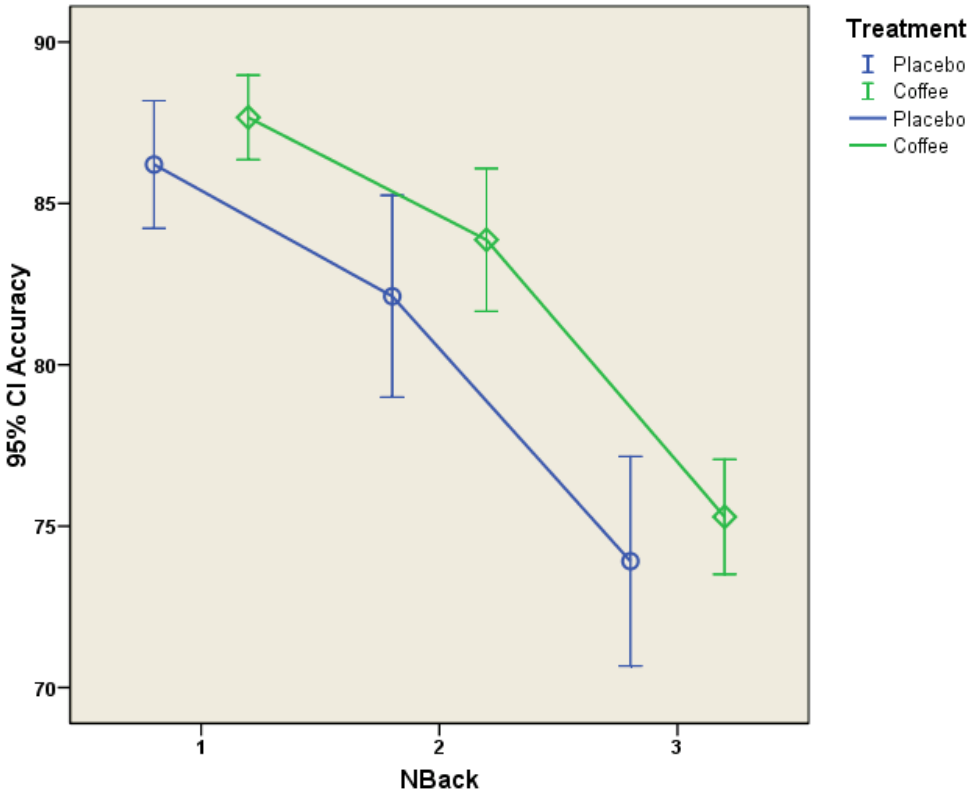


**Figure 6.8:** Accuracy levels visual comparison: 95% confidence interval for the mean reaction time for placebo and coffee ingestion, estimated by n-back: 1-back, 2-back, and 3-back.

**Table 6.5:** Data exhibited in Fig. 6.8, is not statistically different.

| Targets | *t*-value | *df* | *p* |
|---|---|---|---|
| 1-back | 1.272 | 46 | .210 |
| 2-back | .945 | 46 | .349 |
| 3-back | .768 | 46 | .446 |

Accuracy is relatively high in all conditions in the caffeine group.

**Table 6.6:** Test of between-subject effects. The dependent variable is improvement.

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 430.778[a] | 5 | 86.156 | 2.899 | .020 |
| Intercept | 168.056 | 1 | 168.056 | 5.656 | .020 |
| n-Back_pair | 1.861 | 2 | .931 | .031 | .969 |
| Paired | 296.056 | 1 | 296.056 | 9.963 | .002 |
| n-Back_pair * Paired | 132.861 | 2 | 66.431 | 2.236 | .115 |
| Error | 1961.167 | 66 | 29.715 | | |
| Total | 2560.000 | 72 | | | |
| Corrected Total | 2391.944 | 71 | | | |

[a] R-Squared = 0.180 (Adjusted R-Squared = 0.118)

# Chapter 7

# DISCUSSION

Caffeine was associated with a significant increase in alertness and results were significant. However, there was no significant enhancement on cognition. There was no significant relationship between the intake of caffeine and cognitive task. Analyses between caffeine/placebo conditions, found significant results in 1-back and 2-back. On the other hand, results were not significant with n-back 3. This performance decrement could be due to familiarity of content, and counteracted by caffeine (Deslandes *et al.*, 2005). Briefly summarising, across subjects, accuracy was higher, and RT faster, in the low-load WM task compared with the high-load WM tasks.

Optimal level of performance was achieved with caffeine, when comparing the two groups in Fig. 6.1, providing support for the hypothesis, that caffeine improved response time. Whereas MRT was slightly higher for the coffee group in the 3-back task, this could be attributed to memory load or other variables. It can be clearly

observed that MRT increases with memory load of n-back 3 in both group conditions. As the task difficulty and memory load increased, reaction time also increased. The 3-back task required judging whether an item matched any item up to and including 3-back. Reduced MRT suggests that three items could not be effectively maintained in focal attention. These results indicate that focal attention has a much smaller capacity than has typically been assumed (Cowan, 2008).

The ANOVA supports earlier findings which indicated that taking coffee first, then a placebo had some effect in the second test. Although the task was counterbalanced across subjects so as to control for task practice effects, it still seemed that group B fully or partially were alert in session one to enable familiarity in Session 2. This however did not occur when the group ingested Placebo first. There was no speed-accuracy trade off and accuracy since all subjects found the 3-back task difficult in all 4 sessions and RTs were slower. Data shows that the n-back judgements are in part mediated by a search process, and that the complexity of the search depends on 'n'.

Inter-subject variability poses a different problem, in that no standard method has emerged for reliably comparing activity across subjects (Braver *et al.*, 1997).

A possible explanation of these results could be due to testing bias, that is, exposure to the n-back test originally leads to better results the second time. This could be due to the nature of the test, rather than any treatment effects. Therefore, it is reasonable to conclude that having practised the n-back task over 90 trails, thrice, and

familiarity of content, enables participants to improve MRT in group having placebo second, rather than the effects of treatment? Perhaps the measures are not reflective of arousal rather indicators of task related difficulty.

As expected increasing WM load was associated with declining accuracy and performance tended to decrease as memory load increased.

Performance declines continuously with increased task load. The behavioural findings also indicate that both accuracy and speed declined monotonically with increases in task load. Note that the 3-back task differs considerably. The statistical analysis of Smith and Jonides stated that there are 22 significant sites of activation in both 2-back and 3-back tasks, but only 2 significant areas in 0, and 1-back (Smith and Jonides, 1997). These results support previous studies that as memory load increases, more areas in the brain are recruited to perform the task.

The primary purpose of this study was to determine whether caffeine improved cognition. The empirical results obtained did not support a strong correlation. The second aim was to test whether caffeine improved accuracy and this objective was accomplished by comparing the behavioural data obtained during the WM task performance (Gevins et al., 1996 and Gevins et al., 2000). With respect to the performance data, significantly shorter response times were recorded for the caffeine rather than the placebo condition. Findings in this research project are discussed below.

## 7.1 n-Back, Working Memory, and Cognitive Ability

Previous research on n-back studies has elaborated the temporal pattern and neuron mapping. The n-back task requires the following processes:

(a) Encoding a stimulus

(b) Matching it to a representation of the item n-back

(c) Responding on the basis of this comparison

(d) Updating the n items that need to be kept in an active state and their temporal codes

(e) Storing these items and their temporal codes

(f) Rehearsing these items and codes.

It was found that whilst performing n-back 1 task, subjects were able to accomplish this task accurately without coding the temporal order of the stored letters and did not have to be concerned about spurious matches. However, this theory does not apply to 2-back and 3-back tasks. As explained by Smith *et al.* (1998), there is no way to perform the task accurately without coding the order of the stored item. In the 3-back task, participants had to remember the last three letters presented, but had to code the stored letters with respect to their temporal position (only a match 3-back counts) and inhibit responding to matches 1-back and 2-back.

As the n-back task imposes increasing processing loads on WM, there is increased involvement of the prefrontal cortex and other specific networks of activation that occur through the posterior parietal cortex. Reaction times increase monotonically whilst accuracy scores decrease linearly (Braver *et al.*, 1997; Callicot *et al.*, 1999; Callicot and Mattay, 2003; Carlson *et al.*, 1998).

Another reason or alternative interpretation of the data could predict that when memory load increases, it is followed by decreasing activation as subjects become overwhelmed and subsequently disengage from task. Calicott *et al.* claimed that many tasks measure the unitary phenomenon 'working memory' (Calicott *et al.*, 1999). While all subjects have to hold information over a delay, they all probably differ in the relative amount of other component processes (e.g. encoding, recognition, manipulation, inhibition, or forgetting). In this sense the version of the 3-back task was particularly demanding on the encoding and forgetting aspects of working memory (i.e., shutting information and managing interference). In addition to remembering and any inference may have entailed greater cognitive workload than recognition type delayed memory tasks (Calicott *et al.*, 1999). Alan Baddeley in "Looking back and Looking forward", concluded that behaviour is clearly determined not by a simple chain of cause and effect, but rather by a range of controlling factors that operate simultaneously at many different levels, often implicit, but sometimes explicit. This describes only one account of its underlying processes in the role of working memory and further studies are required to be fully understood.

Findings from Hockey and Geffen (2004), suggested that the frontal areas are sensitive to the level of difficulty of the WM task (1, 2, and 3) as well as familiarity of task demands which may have accounted for a different trend for group B who ingested placebo in session 2.

# Chapter 8

# CONCLUSIONS

Based on the empirical results obtained in this thesis it can be concluded that changes produced by caffeine ingestion support the hypothesis that caffeine acts as a stimulant. However, it cannot be proven that the stimulant translates into enhanced motor processes with an improvement in performance. Improved performance through ingestion of caffeine may be evident in a fatigue situation. However, to verify this assumption additional studies are needed to better understand the mechanisms of how caffeine influences WM, as the underlying fundamental processes are still unclear. In the present work, caffeine showed no effect on performance and it can be suggested that caffeine had no large effects on cognitive tasks (Isoardi, 1999).

Could a third session of the n-back task determine differences that this (two session) study was unable to detect? In this study, participants showed an improvement and an impairment which could mean that the improvement and impairment of a drug

such as caffeine is strongly dependent on the nature of the task (Childs *et al.*, 2006).

## 8.1 Future Work

Coffee as a beverage and its popularity in society definitely warrants additional investigation. Consequently, large scale studies need to be undertaken to affirm caffeine's possible effectiveness on specific cognitive functions and working memory. Testing would require replication, and inclusion of a third session that would result in a broader range of scores.

Investigators would have to be mindful that the dual-task nature of the n-back, such as encoding, matching, responding, updating, storing and rehearsing demands, vary greatly between individuals due to (demographics, education and social status). This perhaps may pose as a potential problem. To date, little is known about the sequence of events or neural pathways whilst performing the WM task. Although calculation of response times and accuracy levels assist to a degree, further studies are required to account for subtleties. This thesis offered one more account to add to its underlying processes.

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# Appendix

# CAFFEINE STUDY

The appendix presents material used in organising and conducting the caffeine study carried out for this thesis.

## A.1 Participant Recruitment

In order to attract participants flyers were prominently displayed at RMIT and Swinburne Universities. A sample of this flyer is shown in Fig. A.1.

# Caffeine Study

## Research Participants Wanted

Swinburne University is conducting a study examining the effects of caffeine on human brain activity and performance.

Participation will involve two 3.5 hour sessions at the Brain Sciences Institute. Non-smoking, regular caffeine (coffee, tea and cola products) drinkers within the age range 20-40 are welcome.

Monetary compensation for out-of-pocket expenses will be given to each participant.

If you are interested in participating in this research or would like more information please contact:

Lorraine: lorraine.valladares@rmit.edu.au
Phone: 9925 1971

*recent or regular users of any illicit/recreational drug will not be able to participate

BRAIN SCIENCES INSTITUTE

ACRBR
Australian Centre for RF Bioeffects Research

SWINBURNE UNIVERSITY OF TECHNOLOGY

**Figure A.1:** Flyer to advertise the caffeine study.

# A.2 Questionnaire for Participant Selection

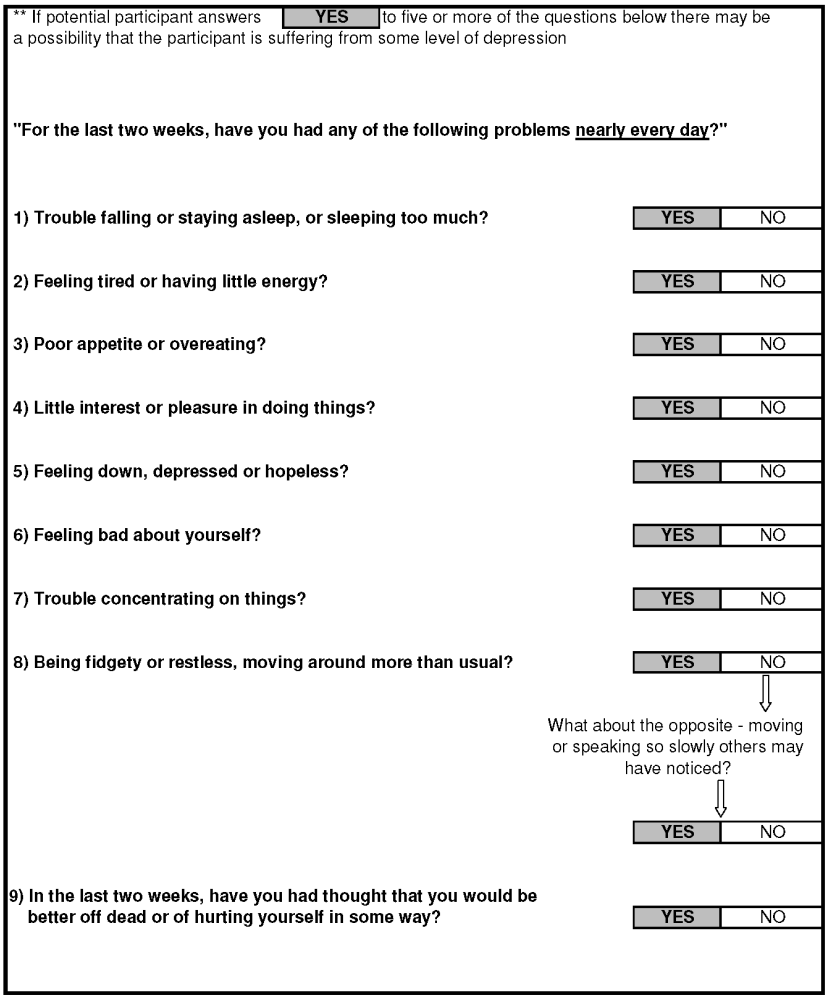
The following questionnaire was used to establish the suitability of the participant for this caffeine study.

**THE EFFECTS OF CAFFEINE ON BRAIN PROCESSING**
**INITIAL PARTICIPANT QUESTIONNAIRE**
**Date:**
**Investigator:**

"Please note that the study is now two 3.5 hour sessions long, and payment will be $100

To be done over the phone at time of first contact with potential participant: " I need to ask you a number of questions, which you are not obliged to answer in order to determine your suitability as a participant in this study. It will takefive minutes to complete and when we finish I will be able to tell you if you are suitable to be testedand we can organise a time for you to come in. Is this a convenient time?"

| | | |
|---|---|---|
| **1) Do you regularly (i.e 8-14 times a week) drink caffeine** | **YES** | NO |
| **(tea, coffee, cola products) a) if so, how much** | | cups/day |
| **b) how often** | | days/month |
| *** If "NO" to question 1: **EXCLUDE**. DO NOT continue and record name*** | | |
| **2) Do you regularly use any illicit/recreational drug?** | **YES** | NO |
| More than once a month Including cannabis, amphetamines, heroin | | |
| **3) Have you used any illicit/recreational drug over the last seven days?** | **YES** | NO |
| *** If "yes" to either question 2/3: **EXCLUDE**. DO NOT continue and record name*** | | |
| Explain that exclusion is necessary to avoid adverse effects that such drugs may have on study results | | |
| **4) Are you lactose intolerant??** | **YES** | NO |
| **5) Does anyone in your family have a history of psychological/psychiatric disorders?** | **YES** | NO |
| *** If "yes" to question 4 or 5: **EXCLUDE**. DO NOT continue and record name*** | | |
| **6) Do you smoke?** | **YES** | NO |
| *** If "yes" to question 6: **EXCLUDE**. DO NOT continue and record name*** | | |
| **7) Are you taking any form of medication/herbal supplements** | **YES** | NO |
| *** If "yes" to question 7: **EXCLUDE**. *** | | |
| **Explain that other forms of medication (e.g. Asthma treatment) or herbal supplements may interact with caffeine administration resulting in adverse effects** | | |
| **8)Do you have a history of unstable/high blood pressure/heart problems??** | **YES** | NO |
| *** If "yes" to question 8: **EXCLUDE**. *** | | |
| **Explain that dose of caffeine utilised in the study may adversly affect their blood pressure** | | |
| **9) What is your age?** | | |
| Does the participant fall within the appropriate age range? | **YES** | NO |
| 20-40 yrs old | | |
| **10) Do you have any history of epilepsy?** | **YES** | NO |
| **11) Have you ever had a serious head injury or been unconscious for more than one hour?** | **YES** | NO |
| **12) Do you have any history of depression?** | **YES** | NO |
| **13) Do you have any known hearing or visual problems?** | YES | NO |
| Auditory or Visual | | |
| Corrected to normal, i.e. glasses? | | |
| | YES | NO |


** If potential participant answers YES to five or more of the questions below there may be a possibility that the participant is suffering from some level of depression
"For the last two weeks, have you had any of the following problems nearly every day?"
1) Trouble falling or staying asleep, or sleeping too much?
YES NO
2) Feeling tired or having little energy?
YES NO
3) Poor appetite or overeating?
YES NO
4) Little interest or pleasure in doing things?
YES NO
5) Feeling down, depressed or hopeless?
YES NO
6) Feeling bad about yourself?
YES NO
7) Trouble concentrating on things?
YES NO
8) Being fidgety or restless, moving around more than usual?
YES NO
What about the opposite - moving or speaking so slowly others may have noticed?
YES NO
9) In the last two weeks, have you had thought that you would be better off dead or of hurting yourself in some way?
YES NO

**INITIAL PARTICIPANT QUESTIONNAIRE - Anxiety module**

Indication of anxiety level

** If potential participant answers **YES** to five or more of the questions below there may be a possibility that the participant is suffering a substantial level of anxiety

**"Over the last two weeks, have you had any of the following problems nearly every day?"**

| | | |
|---|---|---|
| **1) "Nerves" or feeling anxious or on edge?** | **YES** | NO |
| **2) Worrying about a lot of different things?** | **YES** | NO |
| **3) Feeling short of breath?** | **YES** | NO |
| **4) Heart racing, pounding, or skipping?** | **YES** | NO |
| **5) Chest pain or pressure?** | **YES** | NO |
| **6) Did you tremble or shake?** | **YES** | NO |
| **7) Did you have hot flushes or chills?** | **YES** | NO |
| **8) Did you feel dizzy, unsteady or faint?** | **YES** | NO |
| **9) Were you afraid you were dying?** | **YES** | NO |

"Now I am going to tally up your answers and see whether you are suitable to participate…. "

**EXCLUDE?**

If you have circled any shaded box on page 1 **EXCLUDE**
If the participant has answered **YES** to five or more questions regarding depression **EXCLUDE**
If the participant has answered **YES** to five or more questions regarding anxiety **EXCLUDE**

"Okay, I have looked over all of your answers and unfortunately you are unable to participate in the current study. This is not due to one particular answer you have given, rather the overall profile".

**OR** "Okay, I have looked over all of your answers and you do meet the criteria for participation. The next step is to organise a session time for you….."

**mention length of session and basic protocol**

* Finally, we do have to let you know that participants will be excluded if they have used any illicit drug within one week of testing
* We also ask that you do not consume alcohol within 24 hours of testing

## A.3 Raw Data for Sample Participant

The raw data collected over two sessions for the three n-back tests (equivalent to 6 n-back tasks) for a sample participant is presented in Fig. A.2.

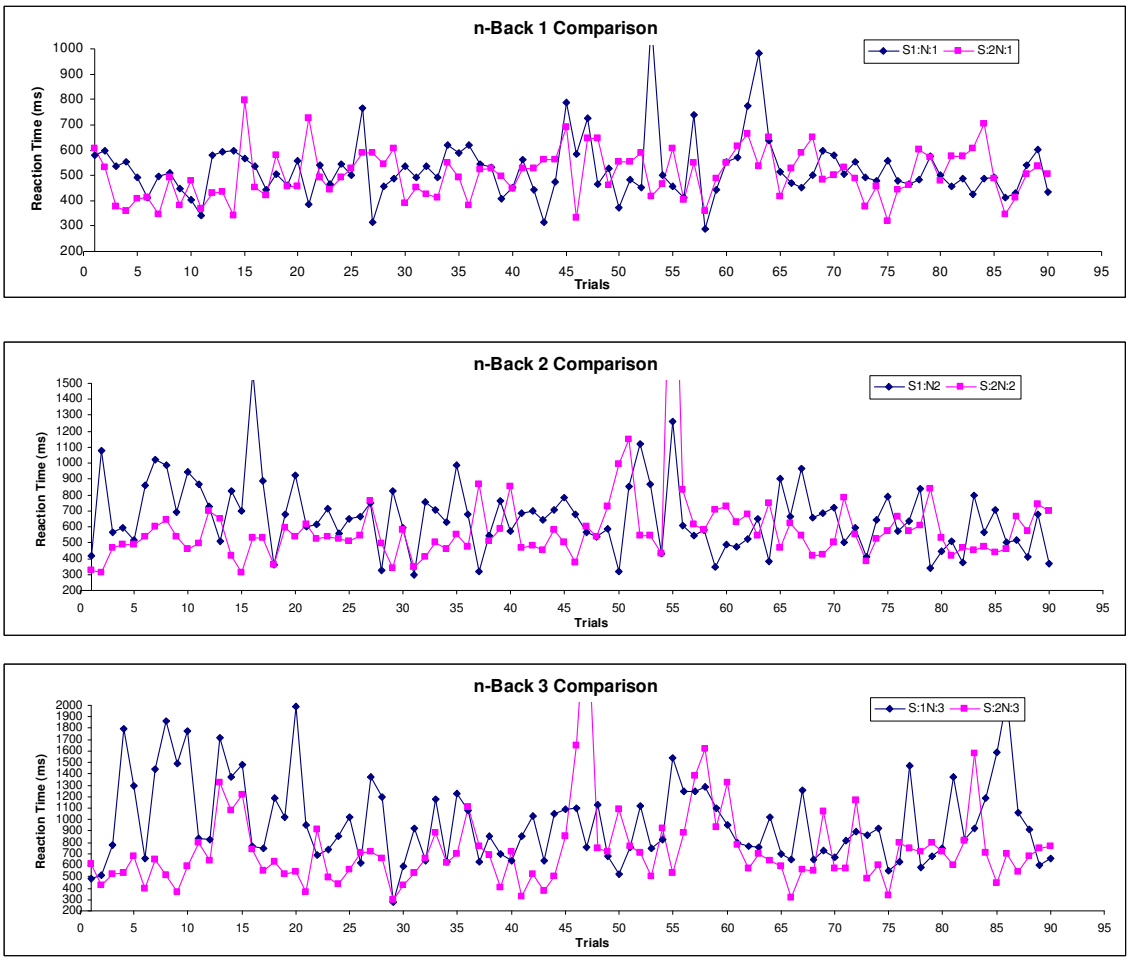



**Figure A.2:** Mean reaction time for individual trials for one participant. 'S' indicates the session number and 'N' indicates the n-back test level.

## A.4 Comparison of Raw Data for Participant Groups

The raw data for mean response time and accuracy for both groups of participants are presented in this section. As the tests were carried out under double blind conditions, the conditions were initially labelled 'A' and 'B'. For both groups, condition 'A' is consumption of placebo and 'B' is for coffee.


**Figure A.3:** Mean reaction time for the two groups of participants in this study. Results for condition A (green) and condition B (orange) are shown.

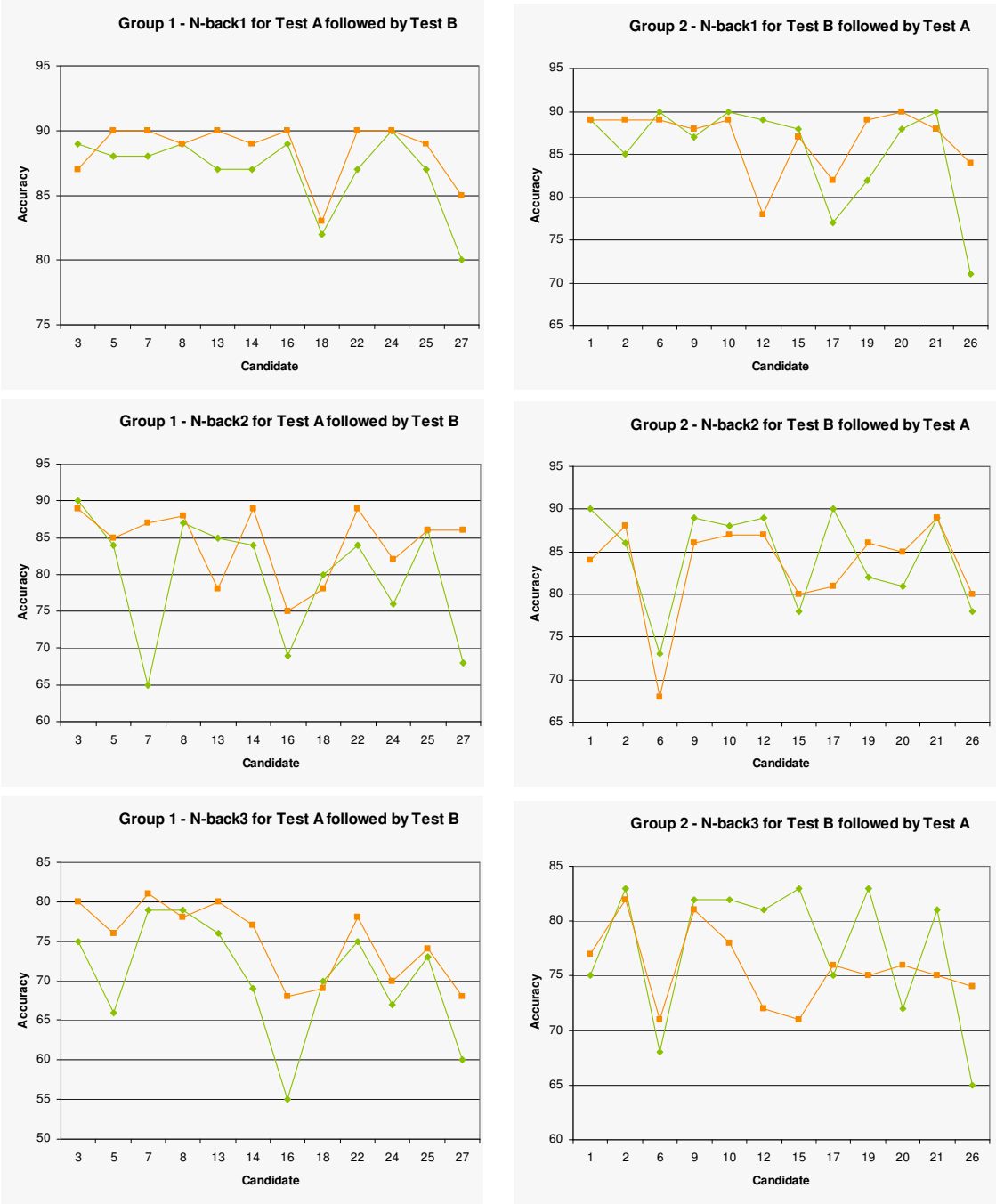
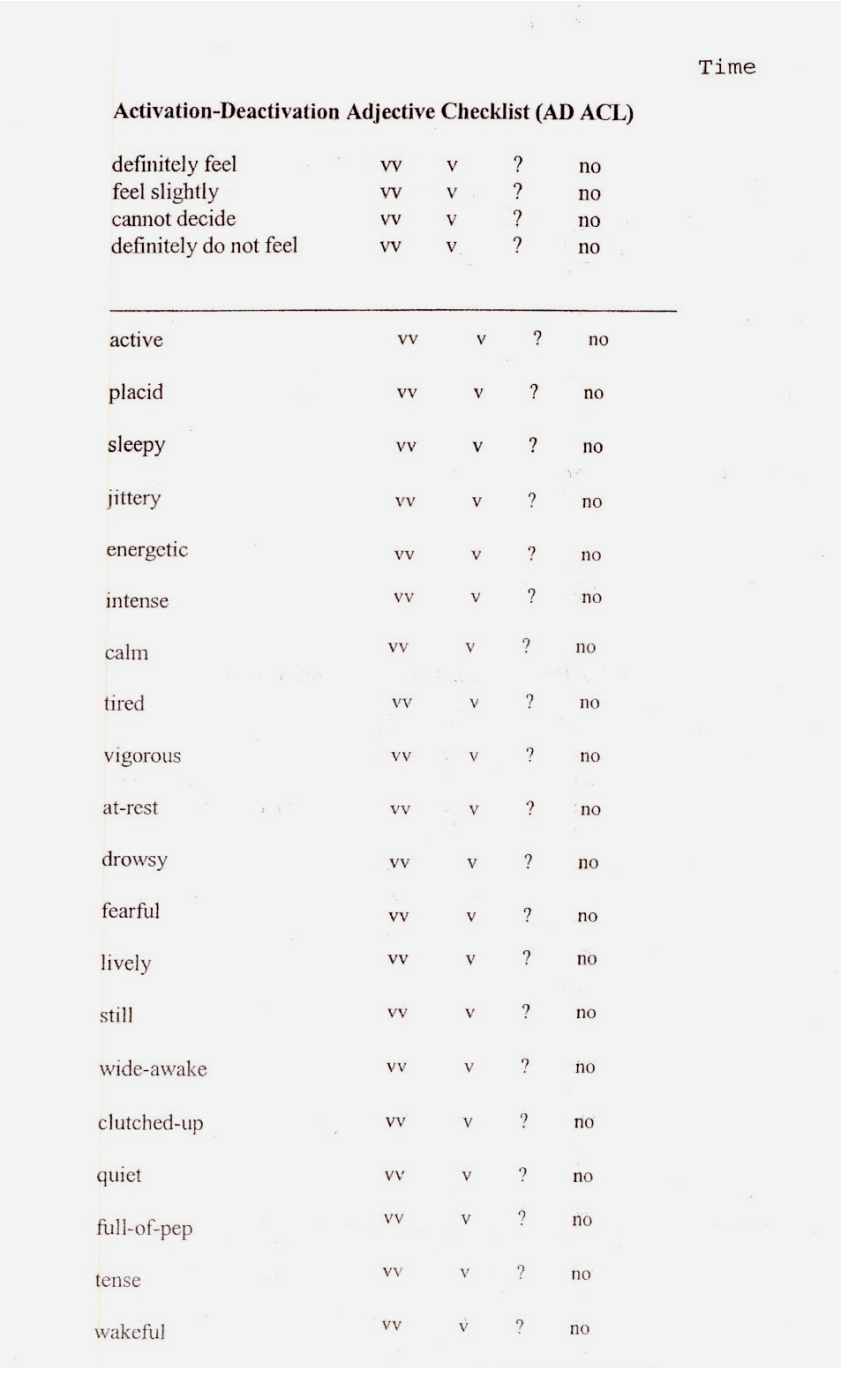



**Figure A.4:** Accuracy for the two groups of participants in this study. Results for condition A (green) and condition B (orange) are shown.

# A.5 Sample AD-ACL Questionnaire



Time

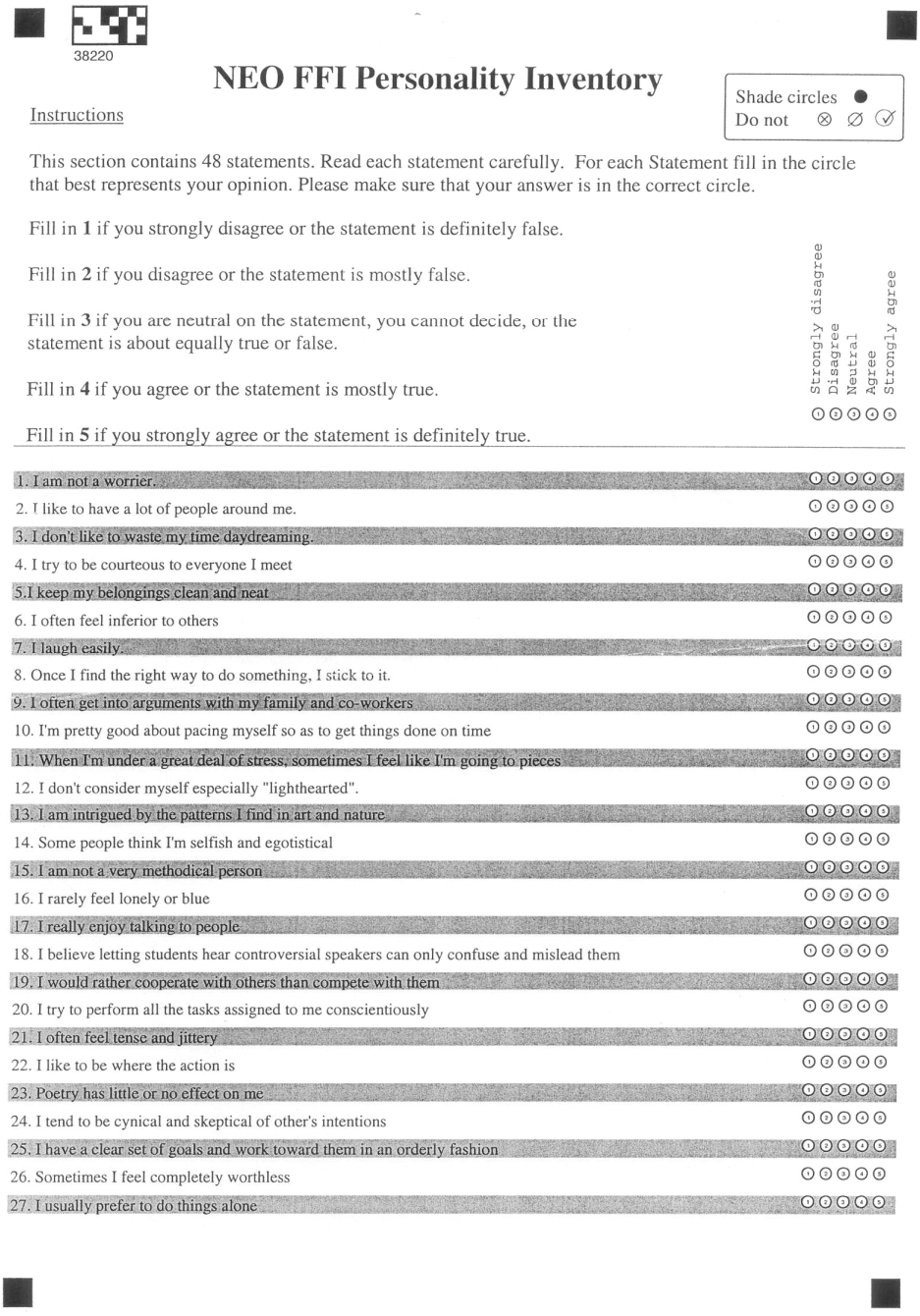
**Activation-Deactivation Adjective Checklist (AD ACL)**

| | | | | |
|---|---|---|---|---|
| definitely feel | vv | v | ? | no |
| feel slightly | vv | v | ? | no |
| cannot decide | vv | v | ? | no |
| definitely do not feel | vv | v | ? | no |

| | | | | |
|---|---|---|---|---|
| active | vv | v | ? | no |
| placid | vv | v | ? | no |
| sleepy | vv | v | ? | no |
| jittery | vv | v | ? | no |
| energetic | vv | v | ? | no |
| intense | vv | v | ? | no |
| calm | vv | v | ? | no |
| tired | vv | v | ? | no |
| vigorous | vv | v | ? | no |
| at-rest | vv | v | ? | no |
| drowsy | vv | v | ? | no |
| fearful | vv | v | ? | no |
| lively | vv | v | ? | no |
| still | vv | v | ? | no |
| wide-awake | vv | v | ? | no |
| clutched-up | vv | v | ? | no |
| quiet | vv | v | ? | no |
| full-of-pep | vv | v | ? | no |
| tense | vv | v | ? | no |
| wakeful | vv | v | ? | no |

**Figure A.5:** Activation-Deactivation Adjective Check List (AD ACL). A self administered scale that lists various transitory arousal states.

# A.6 NEO FFI PI-R



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## NEO FFI Personality Inventory

Shade circles ●
Do not ⊗ ∅ ✓

Instructions

This section contains 48 statements. Read each statement carefully. For each Statement fill in the circle that best represents your opinion. Please make sure that your answer is in the correct circle.

Fill in **1** if you strongly disagree or the statement is definitely false.

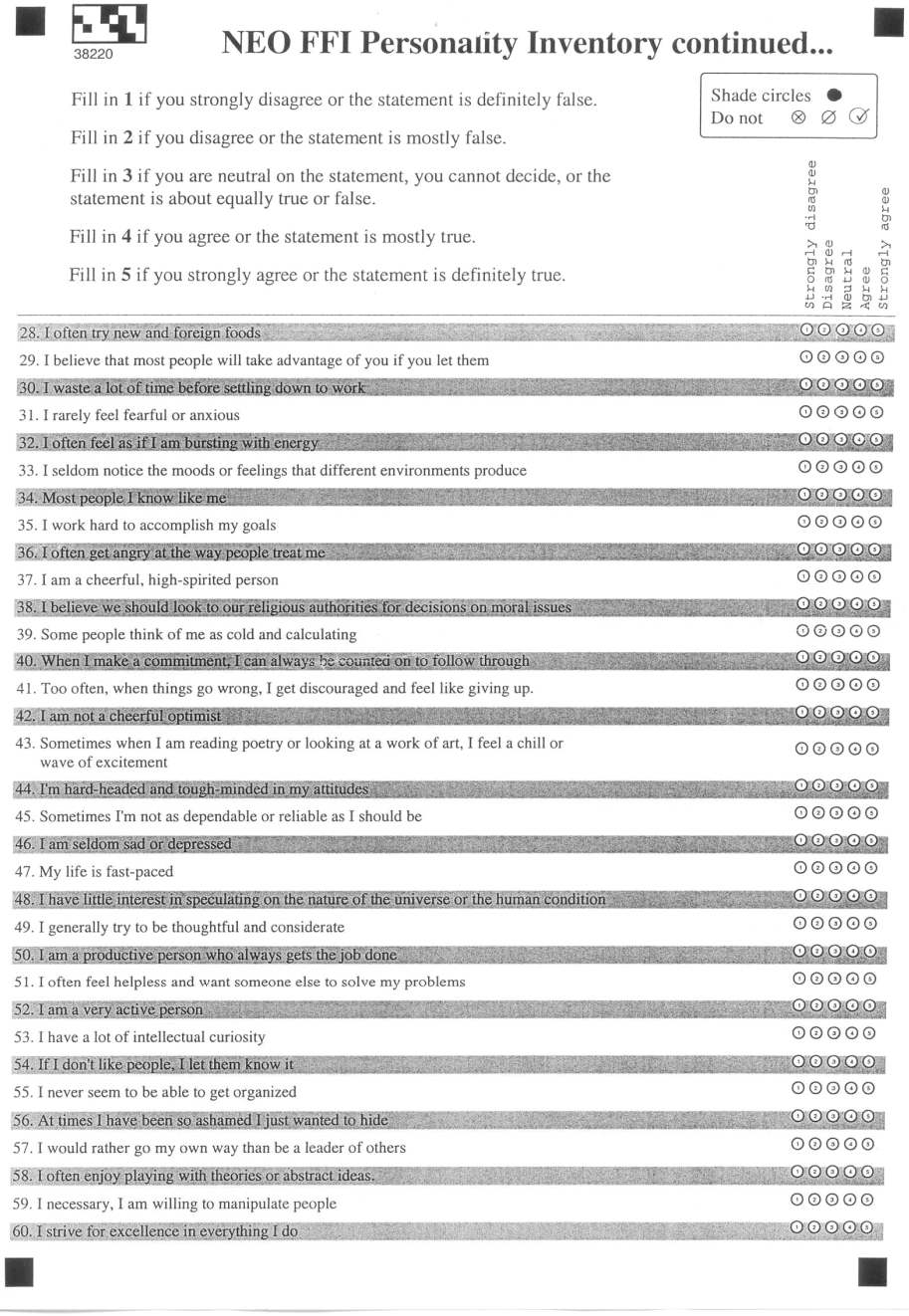
Fill in **2** if you disagree or the statement is mostly false.

Fill in **3** if you are neutral on the statement, you cannot decide, or the statement is about equally true or false.

Fill in **4** if you agree or the statement is mostly true.

Fill in **5** if you strongly agree or the statement is definitely true.

| | 1 Strongly disagree | 2 Disagree | 3 Neutral | 4 Agree | 5 Strongly agree |
|---|---|---|---|---|---|
| 1. I am not a worrier. | | | | | |
| 2. I like to have a lot of people around me. | | | | | |
| 3. I don't like to waste my time daydreaming. | | | | | |
| 4. I try to be courteous to everyone I meet | | | | | |
| 5.I keep my belongings clean and neat | | | | | |
| 6. I often feel inferior to others | | | | | |
| 7. I laugh easily. | | | | | |
| 8. Once I find the right way to do something, I stick to it. | | | | | |
| 9. I often get into arguments with my family and co-workers | | | | | |
| 10. I'm pretty good about pacing myself so as to get things done on time | | | | | |
| 11. When I'm under a great deal of stress, sometimes I feel like I'm going to pieces | | | | | |
| 12. I don't consider myself especially "lighthearted". | | | | | |
| 13. I am intrigued by the patterns I find in art and nature | | | | | |
| 14. Some people think I'm selfish and egotistical | | | | | |
| 15. I am not a very methodical person | | | | | |
| 16. I rarely feel lonely or blue | | | | | |
| 17. I really enjoy talking to people | | | | | |
| 18. I believe letting students hear controversial speakers can only confuse and mislead them | | | | | |
| 19. I would rather cooperate with others than compete with them | | | | | |
| 20. I try to perform all the tasks assigned to me conscientiously | | | | | |
| 21. I often feel tense and jittery | | | | | |
| 22. I like to be where the action is | | | | | |
| 23. Poetry has little or no effect on me | | | | | |
| 24. I tend to be cynical and skeptical of other's intentions | | | | | |
| 25. I have a clear set of goals and work toward them in an orderly fashion | | | | | |
| 26. Sometimes I feel completely worthless | | | | | |
| 27. I usually prefer to do things alone | | | | | |



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## NEO FFI Personality Inventory continued...

Fill in **1** if you strongly disagree or the statement is definitely false.

Fill in **2** if you disagree or the statement is mostly false.

Fill in **3** if you are neutral on the statement, you cannot decide, or the statement is about equally true or false.

Fill in **4** if you agree or the statement is mostly true.

Fill in **5** if you strongly agree or the statement is definitely true.

Shade circles ●
Do not ⊗ ∅ ✓

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| 28. I often try new and foreign foods | 1 | 2 | 3 | 4 | 5 |
| 29. I believe that most people will take advantage of you if you let them | 1 | 2 | 3 | 4 | 5 |
| 30. I waste a lot of time before settling down to work | 1 | 2 | 3 | 4 | 5 |
| 31. I rarely feel fearful or anxious | 1 | 2 | 3 | 4 | 5 |
| 32. I often feel as if I am bursting with energy | 1 | 2 | 3 | 4 | 5 |
| 33. I seldom notice the moods or feelings that different environments produce | 1 | 2 | 3 | 4 | 5 |
| 34. Most people I know like me | 1 | 2 | 3 | 4 | 5 |
| 35. I work hard to accomplish my goals | 1 | 2 | 3 | 4 | 5 |
| 36. I often get angry at the way people treat me | 1 | 2 | 3 | 4 | 5 |
| 37. I am a cheerful, high-spirited person | 1 | 2 | 3 | 4 | 5 |
| 38. I believe we should look to our religious authorities for decisions on moral issues | 1 | 2 | 3 | 4 | 5 |
| 39. Some people think of me as cold and calculating | 1 | 2 | 3 | 4 | 5 |
| 40. When I make a commitment, I can always be counted on to follow through | 1 | 2 | 3 | 4 | 5 |
| 41. Too often, when things go wrong, I get discouraged and feel like giving up. | 1 | 2 | 3 | 4 | 5 |
| 42. I am not a cheerful optimist | 1 | 2 | 3 | 4 | 5 |
| 43. Sometimes when I am reading poetry or looking at a work of art, I feel a chill or wave of excitement | 1 | 2 | 3 | 4 | 5 |
| 44. I'm hard-headed and tough-minded in my attitudes | 1 | 2 | 3 | 4 | 5 |
| 45. Sometimes I'm not as dependable or reliable as I should be | 1 | 2 | 3 | 4 | 5 |
| 46. I am seldom sad or depressed | 1 | 2 | 3 | 4 | 5 |
| 47. My life is fast-paced | 1 | 2 | 3 | 4 | 5 |
| 48. I have little interest in speculating on the nature of the universe or the human condition | 1 | 2 | 3 | 4 | 5 |
| 49. I generally try to be thoughtful and considerate | 1 | 2 | 3 | 4 | 5 |
| 50. I am a productive person who always gets the job done | 1 | 2 | 3 | 4 | 5 |
| 51. I often feel helpless and want someone else to solve my problems | 1 | 2 | 3 | 4 | 5 |
| 52. I am a very active person | 1 | 2 | 3 | 4 | 5 |
| 53. I have a lot of intellectual curiosity | 1 | 2 | 3 | 4 | 5 |
| 54. If I don't like people, I let them know it | 1 | 2 | 3 | 4 | 5 |
| 55. I never seem to be able to get organized | 1 | 2 | 3 | 4 | 5 |
| 56. At times I have been so ashamed I just wanted to hide | 1 | 2 | 3 | 4 | 5 |
| 57. I would rather go my own way than be a leader of others | 1 | 2 | 3 | 4 | 5 |
| 58. I often enjoy playing with theories or abstract ideas. | 1 | 2 | 3 | 4 | 5 |
| 59. I necessary, I am willing to manipulate people | 1 | 2 | 3 | 4 | 5 |
| 60. I strive for excellence in everything I do | 1 | 2 | 3 | 4 | 5 |

**Figure A.6:** Self-administered questionnaire to record personality traits using NEO-FFI.