To what extent does working from a standing desk affect working memory?

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Abstract

Many people in the workforce currently sit for prolonged periods throughout the workday. This increase in sedentary behaviour has been linked with negative health effects. It has been shown that these effects occur independently of the amount of exercise an individual participates in outside these sitting periods, thus standing desks could be a way to reduce sedentary behaviour in the workplace. However, there are some concerns about how the user’s work performance could be impacted by standing desks. This study aims to examine the effects of standing and sitting on cognitive performance, to better understand the implications of standing in the workplace. This study is a counterbalanced, randomised, crossover design of 30 healthy adults aged 18-50 years. Participants were required to perform a 7.5-hour day of cognitive tasks, simulating the cognitive load of a typical workday.

This thesis investigated changes in working memory performance during standing compared to sitting. Four tasks were used to test working memory: Letter-number sequencing, Arithmetic (both adapted from the Wechsler adult intelligence scale version 4, WAIS-IV), Visual reproduction and Spatial span (adapted from the Wechsler memory scale version 4, WMS-IV). Performance was measured at three time points across each testing day (Morning, Midday and Afternoon), with randomly allocated standing or sitting condition for the first day, followed by a one-week minimum washout period, and the alternative standing or sitting condition for the final study day.

A within-subjects analysis was conducted using two-way repeated measure ANOVAs to identify main effects of Condition and Time of Day on each measure. The results of this study found a significant improvement in working memory performance for the Spatial span task when using a standing desk ($p = 0.015$). The other three tasks showed there was no significant difference in working memory abilities when sitting or standing. These findings suggest that it is unlikely the work performance of healthy adults will be negatively impacted by the introduction of a standing desk. Individual’s work performance may even be improved by using a standing desk, during particular tasks that require visuospatial working memory ability. These promising data will encourage those who are considering implementing a standing desk in the workplace, to counter the deleterious health effects of a sedentary lifestyle.
Chapter One – Literature Review

Introduction

When ideal conditions between the worker and their surrounding environment are provided, worker fatigue and discomfort are reduced which may lead to increased work productivity (Bohle et al., 2008). Increased productivity leads to positive outcomes for businesses in both the public and private sectors, which overall is economically important to New Zealand. The relationship between the worker and their work environment is so important that there is ergonomics research, which is a complete field of study dedicated to elucidating and improving peoples’ efficiency in their work environment (“Ergonomics,” 2015).

Traditional office workplace layouts are often stationary workstations with a desk and chair configuration. The worker typically spends the majority of their day sitting at a desk to complete their workload. It is now widely accepted that sedentary behaviour results in negative health outcomes (World Health Organization, 2015), for example – an occupational sitting time of six hours or more per day is associated with obesity in workers (Mummery, Schofield, Steele, Eakin & Brown, 2005). As technology increases and progresses in workplaces, information is becoming the main commodity. Along with an increase in the mechanisation of primary industries, these industries now involve work tasks which no longer require workers to be physically active (Bohle et al., 2008). Workers will then seek to fulfil their physical activity requirements outside of the workplace in their recreational time. This applies pressure on an already narrow window of time, when the demands of family and social life commitments also need to be accommodated.

The overall burden of non-communicable disease facing New Zealand has considerable scope for prevention - with tobacco, diet, physical activity, alcohol, obesity and diabetes all considered to be modifiable risks to health (Ministry of Health, 2013). Physical activity is not only considered a preventative medicine, but is also treatment for conditions such as heart disease, osteoporosis, diabetes and various cancers. In New Zealand “a large proportion of the economic burden [is] associated with treating chronic conditions attributable to physical inactivity” (Auckland council et al., 2013, p. 15) and in 2010 this cost was estimated at $1.3 billion (Auckland Council et al., 2013). Worldwide, it is estimated that inactivity causes 9% of premature mortality, which equates to more than 5-3 million deaths worldwide (based on 2008 figures of a total 57 million deaths worldwide) (Lee et al., 2012). If inactivity was reduced by 25%, then more than 1·3 million deaths would be avoided every year (Lee et al., 2012).

The burden of disease that sedentary behaviour causes is also significant in individuals’ leisure time. It has been estimated that men who spend six hours or more per day of their leisure time sitting have an overall death rate that is 20% higher than men who sit for three hours or less per day (Patel et al., 2010). Women who sit for six hours a day or more
have an estimated 40% higher overall death rate (Patel et al., 2010). Another recent study found for each additional hour of time a person sits watching television per day their risk of dying is increased by 11% (Dunstan et al., 2010).

Taking the above into consideration, it is evident that physical inactivity of workers is becoming a significant risk factor for disease. It has been estimated that half of New Zealand adults do not engage in enough physical activity (which is regarded as at least 30 minutes a day of intentional, structured “movement”, five times a week) and 14% of adults do less than 30 minutes per week (Sport New Zealand, 2015; Ministry of Health, 2014). Although it should be noted these numbers reflect a range of people and situations - some of the people at the lower end of inactivity may be due to physical disabilities (Auckland council et al., 2013).

In support of aforementioned claims, there is a growing body of evidence suggesting that the negative health outcomes associated with sedentary behaviour occur independent of an individual’s exercise levels (Biswas et al., 2015; Dunstan, Howard, Healy & Owen, 2012; Healy et al., 2008; Katzmarzyk, Church, Craig & Bouchard, 2009; Stamatakis, Hamer, & Dunstan, 2011; Wijndaele et al., 2009). Which means an individual still carries the associated risks of a sedentary job or lifestyle, even if they are achieving the suggested 30 minutes of activity, five days a week recommendation. Interestingly however, a recent prospective study by Pulsford, Stamatakis, Britton, Brunner & Hillsdon (2015), found evidence contradicting this trend. In this study, they followed 5132 people over 16 years and found there was no association between five different sitting behaviours and an increased risk of all-causes mortality irrespective of whether moderate to vigorous physical activity occurred. It is possible this result may be an anomaly, since this cohort had an unusually high level of physical activity which may have had a protective effect (Pulsford et al., 2015). Specifically, the sample had high levels of daily walking with a mean reported walking time of 42.68 minutes per day, which is over double the mean reported daily amount in the United Kingdom (Pulsford et al., 2015). Even so, further research will be needed to ascertain the mechanism of sitting that is behind the trend, particularly given that the majority of research to date has found that an increase in sitting time predicts higher mortality risk even when the recommended amount of physical activity is achieved.

In light of these alarming findings it may be suggested that overall better health outcomes for workers could be produced by changing to standing or light activity workstations for use during the workday. Such workstations would minimise the amount of time across the day spent sitting and could help alleviate the associated health risks that come with sedentary work environment. Individuals and employers considering the introduction of standing desks to a work environment are likely to be concerned with how this change in posture could affect their work performance. Cognitive abilities are a major constituent of the overall work performance of workers. Therefore discovering whether cognitive performance is changed
when a worker sits or stands during their work day is important information for employers, individuals and communities.

**Cognitive Performance**

**Cognition and how it is measured.** Cognition can be defined as the integration of multiple brain functions to perform tasks such as problem solving, language and reasoning (Kosslyn, Rosenberg & Lambert, 2014). Cognition can be tested by achievement tests (assessing what an individual has learned) or aptitude tests (predicting what an individual’s performance will be and what they are capable of learning). Intelligence testing measures individuals’ aptitude. Many cognitive tests are focussed around specific functions such as attention, learning or language, and are often for the purpose of detecting cognitive pathologies. Generalised intelligence tests are limited since they fail to measure all types of cognition. They also do not incorporate for emotional intelligence, social intelligence, creativity or motivation (Lefton & Brannon, 2008).

There are several methods of measuring general intelligence, such as the Wechsler adult intelligence scale, Stanford-Binet intelligence scales and Woodcock-Johnson tests of cognitive abilities. The most widely used test of individual intelligence are the Wechsler scales (Lefton & Brannon, 2008; Kosslyn et al., 2014). The Wechsler intelligence scale was first developed in 1939 by David Wechsler with five revisions since then. The fourth and most recent revision was released in 2008 (“Wechsler Adult Intelligence Scale”, 2008).

**Wechsler adult intelligence scale.** The Wechsler adult intelligence scale version 4 (WAIS-IV) is a well-developed and researched test of intelligence. The WAIS-IV has supporting evidence for its validity, based on comparisons with tests of cognitive abilities and academic achievement (Lichtenberger & Kaufman, 2013). The WAIS-IV was standardised with 2,200 people selected according to 2005 United states of America (U.S.) census data. Overall, the WAIS-IV indexes and subtests have strong reliability. The average reliability coefficients for the adult Working Memory Index were 0.94 for split-half reliability and 0.88 for test-retest reliability (Lichtenberger & Kaufman, 2013).

The WAIS-IV measures important cognitive processes that influence a person's Wechsler memory scale (WMS-IV) performance. The WAIS-IV and WMS-IV have no overlap, but were co-developed and co-normalised together which allows comparisons across each scale. The WMS-IV was standardised with 1400 people selected according to 2005 U.S. Census data. The average split-half reliability for adult Visual memory index was 0.96 and for the Visual working memory index 0.93. Test-retest reliability values were 0.8 and 0.82 respectively (Drozdick et al., 2011).
Memory

Memory is an essential component of cognition and is commonly assessed in clinical and neuropsychological settings. Memory function is the ability to recall past events, images, ideas, noises and previously learned information or skills (Cowan, 2008; Lefton & Brannon, 2008). It is also an information storage system that an individual can input and retrieve memories. Memory is aligned with learning, because an individual acquires information by learning and then storing and using the information through their memory system (Lefton & Brannon, 2008).

How memories are processed. The most current theoretical understanding of memory processing encompasses three different types of storage and progresses from sensory to short-term to long-term memory (Lefton & Brannon, 2008). Sensory memory is the brief mechanism that converts incoming sensory stimuli into memory. It is the initial encoding that can store information for up to 0.25 seconds for visual information or 3 seconds for auditory information (Lefton & Brannon, 2008). If information is not quickly transferred to short-term memory it will be lost. Short-term memory is where information is held for processing and lasts 20-30 seconds. It is vulnerable to quick decay and loss if there is no rehearsal to maintain information. Information can then be stored in long-term memory, which is the storage that allows information to be kept for long periods or permanently. Long-term memory storage has a much larger capacity for information than the other memory stores (Lefton & Brannon, 2008).

Within long-term memory there are different types of memory including explicit, implicit, semantic, episodic, procedural and declarative (which will not be elaborated on here). In general memory can be accessed from storage by recalling, recognition or relearning information. We forget information by storage decay and failing to encode or retrieve appropriately (Kosslyn et al., 2014; Lefton & Brannon, 2008). Storage decay occurs over time when a memory is not often used, so the details are slowly lost until the memory is completely unable to be recalled anymore. We also forget memories by failing to encode or retrieve the information (Kosslyn et al., 2014), this may occur because we were distracted by surrounding sensory information at the time of memory input. Or because we have no reference to help trigger the recall of information, for example a photograph, sound or keyword.

Differences between short-term and working memory. Short-term memory and working memory are terms used interchangeably in memory research. The development and modelling of memory function concepts started with short-term memory, first described by Thorndike in 1910 and explored by others in the 1950s. In the 1970s Alan Baddeley and Graham Hitch introduced a comprehensive model of working memory (Smith & Kosslyn, 2007). Working memory is made up of “the components of the whole system that includes short-term memory and the processes that interpret and transform information in short-term memory” (as cited in Kosslyn et al., 2014, p. 265). There is no standardised, universally-
agreed definition of working memory (Berryman et al., 2013) because it has a developing meaning as the understanding and research in this area of neuroscience and psychology progresses.

**Current model of working memory.** Currently, the most influential and widely researched understanding of working memory is the Baddeley-Hitch model (Smith & Kosslyn, 2007). This model shown in Figure 1, is supported by a significant body of research (Baddeley, 2001).

![Figure 1. Baddeley-Hitch working memory model and its component stores (Baddeley, 2001).](image)

Briefly, this involves the Central executive and two subsidiary stores. The first store is the Phonological loop, which involves auditory information and verbal rehearsal. The second store is the Visuospatial sketchpad, which involves visualising or navigating an image, place or symbol. These are integrated and manipulated by the Central executive, which controls which store to use and when (Smith & Kosslyn, 2007). Further development of the model by Baddeley (2001) included the addition of the Episodic buffer store, which has a mixed function of storing temporary events or episodes and integrating visual and auditory information. Baddeley (2001) has suggested future development of this working memory model may place the Episodic buffer as part of the Central executive.

**Effect of Physical Activity on Cognitive Performance**

Physical activity can be defined as any activity that is part of a person's everyday life, usually involving whole body movements and deep skeletal muscles (Bherer, Erickson & Liu-Ambrose, 2013). Studies using this term mostly utilise a variety of unspecified activities such as household chores, the weekly supermarket shop, gardening and so forth. Whereas exercise can be defined as structured and planned activities with the primary purpose of
improving strength, fitness or overall health. Studies using this term usually specify and control the intensity and duration (Bherer et al., 2013). It appears that both physical activity and exercise give cognitive benefits, although they may operate by differing mechanisms which are yet to be elucidated. These differences will not be further elaborated in this review and the term ‘physical activity’ will be used to generally refer to research including both physical activity and exercise.

**How physical activity improves cognition.** Physical activity has been shown to improve cognition in a variety of ways at both the molecular (cellular) and systemic level. At the molecular level, exercise induces many complex genetic and cell-signalling pathways, which are only briefly described here. Firstly, physical activity increases the amount of brain-derived neurotrophic factor (BDNF) which is a protein found in the brain and throughout the muscles in the body (Huang, Larsen, Ried-Larsen, Moller & Andersen, 2014). BDNF is important for brain development and plasticity by allowing the growth and maintenance of neurons and their synaptic connections. BDNF also has a role in energy metabolism including fat burning (Matthews et al., 2009) and it consequently has been linked with metabolic disorders like obesity and diabetes (Fujinami et al., 2008). Physical activity also stimulates an increased production of insulin-like growth factor 1 (IGF-1) which is another protein involved in the growth of new neurons and blood vessels (Bherer et al., 2013). This growth leads to changes in the brain including enlargement of brain regions (such as frontal lobe for executive function and hippocampus for memory) and quicker and more flexible cognitive processing. These changes have all been repeatedly demonstrated in physical activity intervention studies in both animal and human models (Bherer et al., 2013; Ratey & Loehr, 2011). Both immediate and long-term physical activity primes and maintains neural systems that underlie attention, learning, and memory for efficient and flexible functioning (Huang et al., 2014; Ratey & Loehr, 2011; Roig, Nordbrandt, Geertsen & Nielsen, 2013).

Physical activity also improves cognition indirectly by systemic health benefits. This occurs when physical activity incidentally improves stress, sleep and the symptoms of depression, by enhancing mental resources (Spirduso, Francis & MacRae, 2005). Physical activity acts as an adjunctive treatment because it decreases the effects of chronic diseases that impact neurocognitive functions, such as coronary heart disease and diabetes (Bherer et al., 2013). Some other beneficial consequences of physical activity are positive affective and perceptual responses, which can lead to improved cognition. That is, daily physical activity is associated with decreased perceived stress, positive emotions and perceived improved cognitive abilities (Fitzsimmons et al., 2014).

**Different aspects of physical activity.** There has been some research into the type of physical activity that yields the greatest benefit to cognitive ability. Several meta-analyses (Angevaren, Aufdemkampe, Verhaar, Aleman & Vanhees, 2008; Colcombe, & Kramer, 2003; Smith et al., 2010) have confirmed the evidence is stronger that aerobic exercise has the greatest impact on cognitive performance and is especially useful for
executive functions (Bherer et al., 2013). There is emerging evidence that resistance exercise is also beneficial (Kelly et al., 2014), but further studies are needed to confirm and determine the details.

Regular physical activity in adulthood has a significant, lasting impact on cognition (Ohman, Savikko, Strandberg & Pitkälä, 2014; Ratey & Loehr, 2011). The benefits are seen over a range of time frames, immediately and in the long-term reaching later into life. A 20-minute bout of moderate cycling was shown to improve acute performance in an executive cognitive task (which challenged selective attention ability) across participants of all fitness levels (Chang et al., 2014). Not only has acute physical activity helped to improve executive function, but regular physical activity in midlife can have a protective effect against cognitive decline in later years (Bherer et al., 2013; Ratey & Loehr, 2011). There is also research that found physical activity can even benefit older adults who have mild cognitive impairments in attention and executive function (Ohman et al., 2014).

How physical activity effects working memory. There are multiple studies that suggest physical activity has a positive effect on working memory performance (Ratey & Loehr, 2011; Roig et al., 2013). This effect was found across adults aged 17-60 years, both immediately after a single episode of aerobic exercise and after training programmes lasting 2-6 weeks. Immediately after an episode of intense aerobic exercise, working memory (specifically a task involving vocabulary) was improved by 20% (Winter et al., 2007). These findings were similar to those of Pontiflex, Hillman, Fernhall, Thompson, & Valentini (2009) who found an immediate improvement in the efficiency of working memory, with a bout of aerobic exercise but not resistance exercise. When the duration of physical activity increased to a programme of six weeks of running (30 minutes, three times weekly), Stroth, Hille, Spitzer & Reinhardt (2009) found a significant improvement in visuospatial memory and positive mood in young adults. A longitudinal study of 25 middle aged adults, with one year follow up confirmed that the improvements in working memory are not maintained if regular physical activity ceased (Hotting, Schauenburg & Roder, 2012). This means unless regular physical activity is maintained, the benefits it conveys to working memory function will not be retained (Hotting et al., 2012; Winter et al., 2007). These positive findings suggest standing desk interventions that aim to increase the activity of sedentary adults on a regular basis may also change working memory performance.

One such study investigated computer and cognitive task performance in healthy adults using dynamic workstations – standing, treadmill, elliptical trainer and stationery cycling (Commissaris et al., 2014). At an intensity of 25% of the participants’ heart rate reserve (HRR), none of the dynamic workstations showed any change in cognitive performance. Although there was a detrimental effect seen on working memory performance for the cycling workstation at 40% HRR (Commissarlis et al., 2014). These results did not show the predicted positive acute effect on working memory that concurrent moderate aerobic exercise usually gives (Ratey & Loehr, 2011; Quelhas Martins, Kavussanu, Willoughby, & Ring, 2013). This
may be due to the short condition duration of 8 minutes, where previous studies examining acute bouts of aerobic exercise used a minimum of 30 minutes. This short duration also does not reflect a typical office environment, where such workstations are likely to be used across a working day, not for a one-off short 8-minute bout. It should be noted the cognitive measures used in Commissaris et al.’s (2014) study may not have been robust, since they were taken from a website (http://cognitivefun.net) which offers enjoyable cognitive tasks for people to test their abilities, and has no indication of the tasks’ reliability or validity.

Standing Posture

There are multiple potential physiological health benefits to working while standing. For musculoskeletal health, standing is a preferable position compared to sitting. When people are sitting down their lower limbs are held in a shortened, flexed and often immovable position, which diminishes their skeletal muscle pump action. When standing, this pump action helps with blood venous return to the heart and lymphatic drainage of the lower-half of the body (Klabunde, 2008). Similarly, seated posture in the workplace is often accompanied by a slumped upper-body posture. This slumped posture makes the thorax space smaller, limiting the amount of space for lung expansion (Lin et al., 2006). When the lungs cannot expand fully, the amount of gas exchange surface is reduced which means there is a decreased capacity for blood oxygenation, which ultimately will affect the brain receiving the optimal amount of oxygen for peak performance. Thus sitting in a slumped posture may have limiting effects on the brain’s ability to perform cognitive tasks optimally.

If sitting is replaced with physical activity of light to moderate intensity, insulin sensitivity of the body’s tissues is improved, which leads to improved glucose metabolism (Shrestha et al., 2015). It also increases lipoprotein lipase activity that breaks down triglycerides and enhances their uptake into cells (Shrestha et al., 2015). This was also confirmed by Healy, Winkler, Owen, Anuradha & Dunstan (2015) who found that an additional two hours per day spent standing, resulted in a decrease of 14% triglycerides and 6% total/HDL cholesterol ratio. With each additional two hours per day sitting there was a 2cm increase in waist circumference. These results were all statistically significant and above the minimum clinical effect size of interest. Over the long-term these health differences in sitting and standing are beneficial for cardiovascular health and prevention of diabetes (Healy et al., 2015). Stephens, Granados, Zderic, Hamilton & Braun (2011) found insulin action in the body was 39% higher after just one day of standing compared to sitting. When these results were adjusted to balance energy intake with activity output, insulin action was still 18% better when standing than sitting. Duvivier et al. (2013) found that “one hour of daily physical exercise cannot compensate for the negative effects of inactivity on insulin sensitivity and plasma lipids if the rest of the day is spent sitting” (2013, p. 4). They concluded that increasing the amount of time standing or walking during the day is more effective than one hour of exercise per day to reduce the negative health effects associated with physical inactivity (Duvivier et al., 2013).
Working from a standing position also has metabolic benefits for the prevention of obesity due to the extra calories that are used through the day compared to a lesser energy expenditure in a sitting position.

These benefits also need to be balanced with the possible negative effects of standing. This includes physical feelings of fatigue and discomfort in the low back or legs, swelling of the feet and increased spinal loads causing temporary intervertebral space loss (MacEwen et al., 2015). Garcia, Laubli & Martin (2015) investigated physical fatigue and discomfort after a five-hour period of prolonged standing. Objective measures of muscle fatigue and subjective evaluation of discomfort significantly increased after five hours of standing work. But the discomfort and fatigue were no longer perceived after 30 minutes of resting at the end of the five-hour period of standing work (Garcia et al., 2015). Unfortunately, recordings were not taken over a standard eight-hour workday nor were they repeated on consecutive days. For this reason it is hard to make comment on whether these findings are generalizable to a typical work week or how adaptive processes over a longer period would alter these findings. While it has been shown that working from a standing position could have significant musculoskeletal and metabolic health benefits, unfortunately there are concerns as to how it may be used in the working environment for various populations and especially whether it will affect working performance.

**Dual-task costs.** For most people performing both a postural and a cognitive task concurrently is not difficult if the postural task is processed automatically. However, when postural control requires an increased level of central nervous system processing, cognitive resources may be exceeded when an attentionally demanding task is also added. For example, this could range from a distracting noise occurring while walking or trying to navigate a map while standing in a moving train. This causes dual-task costs, which are the interference effects seen between two tasks, that manifest as a decreased performance in one or both tasks (Ruffieux, Keller, Lauber & Taube, 2015).

There has been a large amount of research done on the subject of dual-task costs between postural control and cognitive performance (Boisgontier et al., 2013; Krampe, Schaefer, Lindenberger, & Baltes, 2011; Ruffieux et al., 2015; Stins & Beek, 2012). However, the specific mechanism behind what causes the interference in performance has not been determined. There are two explanations of how dual-task interference effects occur. The *Capacity explanation* suggests that interference occurs due to the simultaneous, parallel sharing of the same cognitive resources. This results in decreased performance on either, or both, postural control and the cognitive task at hand. The *Bottleneck explanation* suggests that interference is due to the dual-task process being sequential, so that the nervous system postpones one task in favour of processing the prioritised task. This results in decreased
performance in either the postural control or cognitive task, whichever is rated a lower priority (Fraizer & Mitra, 2008).

**Specific populations.** It is postulated that children and older adult population groups show pronounced interference between concurrent postural control and cognitive tasks, with a resulting sacrificed performance in one of these (Ruffieux et al., 2015). This was confirmed in older adults in a systematic review of 79 studies, but there is still limited available evidence for increased posture-cognition dual-task costs in children (Ruffieux et al., 2015). Postural instability and the incidence of falls is similar between both children and older adult groups and both populations share similarities in how they process sensory information for postural control (Ruffieux et al., 2015). It has also been found that adults of all ages benefit from practice and training programmes that improve dual-task performance (Doumas, Rapp, & Krampe, 2009; Ruffieux et al., 2015). With training, older adults tend to improve on postural control tasks whereby the younger adults improve on cognition tasks (Doumas et al. 2009). Interestingly, this could be an inherent, automatic prioritisation of the most highly ranked task for that stage of life. Since adults appear to improve cognitive performance with training, this could suggest there is a period of adjustment with a new standing work posture which over time may resolve any increase in cognitive load associated with standing.

The interference caused by dual tasks is more common in elderly, possibly due to a change in their strategy involving the conscious control of balance (Stins & Beek, 2012). This fits with a proposed hierarchical view of motor control that includes posture. Briefly, Glover (2005) describes five levels of motor control – progressing from automatic to conscious control of movement. On the lower levels of this hierarchy, where motor control processes are fast and automatic, these processes are immune to cognitive influences so they are less modifiable by cognition (as cited in Stins & Beek, 2012, p. 215). The higher up the hierarchy a particular task is placed, the greater the amount of conscious control is needed for the motor task and the more cognition will interfere. If this hierarchical view is correct, it will be an important consideration for introducing active workstations into the workplace. Since standing is a less complex postural task than walking or cycling, working at a standing desk is likely to have less interference with cognition than working at a treadmill or cycling desk and thereby standing desks should be a far more feasible intervention to promote health in the workplace.

**Standing posture and working memory.** While there have been a number of studies comparing the effects of simultaneous cognition and postural balance there have also been various investigations specifically into the interaction between concurrent working memory tasks and postural balance in a standing position (Chong et al., 2010; Fraizer & Mitra, 2008; Little & Woollacott, 2014; Ramenzoni, Riley, Shockley & Chiu, 2007). The evidence is still unclear of exactly how this may occur.

When considering the model of working memory which is divided into the differing visuospatial and verbal auditory (or phonological) components, there has been research
suggesting visuospatial working memory performance is greater impacted by standing postural and balance control. One study found during a simultaneous balance control task and visuospatial working memory task involving word generation, that speed and accuracy decreased (Chong et al., 2010). Which could suggest that there is a sensory organisation for balance control which draws on similar visuospatial resources.

Ramenzoni and colleagues (2007) showed that the ability to maintain postural control is altered according to the cognitive load and the type of activity. They found there was variability in postural sway while standing during concurrent working memory input tasks. In this study increased postural sway was interpreted as a sign of decreased postural stability control. Their results showed that during rehearsal (which would require less processing due to its repetitive nature), sway decreased significantly and during encoding (a task which would require greater memory processing), sway increased significantly. This may allude to differing brain structures or pathways activating during the different processes of working memory.

Little & Woollacott’s (2014) investigation of electroencephalogram (EEG) findings in young adults showed that visual working memory capacity was significantly decreased by the interference of postural control on an unstable surface. In this study, participants were asked to stand on a stable surface and on a surface with perturbation (Little & Woollacott, 2014). The reduction of working memory capacity as demonstrated by the EEG results provides objective evidence towards the dual-task cost paradigm - that there is competition for central processing resources.

There is evidence that postural challenges effect visuospatial working memory performance and vice versa adding a visuospatial task increases postural sway (which is interpreted as decreased postural stability control). The former, is of more interest when considering a change in workstation posture. The latter - where postural sway increases with introduced visuospatial working memory load, is a greater consideration for research in older adults, which are mostly outside the typical workforce age group. However, Fraizer & Mitra (2008) reviewed this area of research and some of the conflicting aspects of the dual-task interference effect. They found multiple difficulties with methodologies as well as the theoretical explanations behind this effect. This suggests there is still more research needed before conclusions can be made on how the brain processes standing balance and working memory tasks simultaneously.

Standing and Active Workstations

Recent review findings. Recently there have been four major reviews in the research area of active workstations (Karakolis & Callaghan, 2014; MacEwen, MacDonald & Burr, 2015; Shrestha, Ijaz, Kukkonen-Harjula, Kumar, & Nwankwo, 2015; Torbeyns, Bailey, Bos & Meeusen, 2014). These reviews examined the biophysical and cognitive effects of
introducing these workstations. However, the cognitive outcomes were varied and compared studies discussing similar, but slightly different concepts of cognitive performance, work performance and work productivity. The language used to describe these measures changes from cognitive task performance to work task performance to work productivity measures. These measures vary in their attempts to try and simulate a real-life office work task as closely as possible, to utilising cognitive tests (Banoftet et al. 2015; Commissaris et al., 2014; Ohlinger Horn, Berg, & Cox, 2011; Schreafel et al., 2012; Torbeyns et al., 2014). This makes pooling data across studies and drawing conclusions on the findings difficult because details of methodologies may be unknown or too different to compile.

The first review by Karakolis & Callaghan (2014) looked at 14 studies, specifically on how sit-stand desks impact user discomfort and productivity. These desks allow the user to shift posture throughout the work day as required, to avoid discomfort. Eight studies were included that reported productivity outcomes. One study found mixed productivity results - the completed volume of work increased, but at a lower quality with the sit-stand desks (Hasegawa, Inoue, Tsutsue & Kumashiro, 2001). The remaining seven studies which measured work productivity, found no change in productivity for sit-stand desks (Karakolis & Callaghan, 2014). These consistent findings of no real change in productivity, are promising for businesses who are considering the implementation of these desks to improve the wellbeing of their workers.

Another systematic review of active workstations looked at 32 studies, including 16 studies investigating standing, 15 studies of walking and one study of a cycling workstation (Torbeyns, Bailey, Bos & Meeusen, 2014). Approximately half of the studies were longitudinal and five studies used participants that were school-aged children. Torbeyns et al. (2014) concluded there were clear physiological health benefits for participants. These include decreased sitting time across the day, increased energy expenditure and a positive effect on several health markers. They found there was no acute effect on cognitive function or work performance, however the longitudinal studies included in this review had participants choosing when to use the active workstation, with no minimum amount of time prescribed (Torbeyns et al., 2014). This may mean that participants could choose not to use the active workstation at all, in which case the study would no longer investigate any effect of active workstations.

The most current systematic review investigated standing and treadmill desks and their effect on physiological and psychological outcomes (MacEwen, MacDonald & Burr, 2015). Psychological outcomes included work performance, mood states and cognitive function. Seven reviewed studies showed evidence that treadmill or standing desks allowed for consistent work performance, with no decline up to a year later. One treadmill study showed performance after one year had exceeded baseline performance measurements (Koepp et al., 2013). There were mixed, but positive results for wellbeing outcomes while using standing desks. Factors such as fatigue, vigour, mood and self-esteem improved,
although these effects disappeared and returned to baseline when the standing desk was withdrawn after five weeks. Which may indicate these improvements were transient, temporary effects associated with novelty of using a new workstation setup. For cognitive function outcomes there was no difference found for treadmill desks. There were no studies included in the review with cognitive function outcomes and MacEwen et al. (2015) noted the obvious lack of any strong studies on how standing desks impact cognitive performance. Overall there was no significant differences seen in psychological outcomes when using standing or treadmill desks. This suggests that the thought processes necessary for typical desk work are unaffected and thus there is no detrimental impact on the quality of work being produced (MacEwen et al., 2015).

Finally, a recent Cochrane review (Shrestha, Ijaz, Kukkonen-Harjula, Kumar, & Nwankwo, 2015) evaluated workplace intervention studies to reduce sitting time of workers. Work performance was investigated as a secondary outcome and was measured in three of eight reviewed studies, which were all considered to be at high risk of bias. They found introducing sit-stand work desks had no effect on work productivity at one week follow-up post-intervention. At three months there was a small, non-significant improvement in work performance (mean change of 0.35 points on a 1-10 self-rated performance scale) with the sit-stand work desks. Overall they conclude “the quality of the evidence was very low to low . . . sit-stand desks did not have a considerable effect on work performance” (Shrestha et al., 2015, p. 2). For the other outcome measures reviewed, they found sit-stand desks gave a clear reduction in sitting time (average 113 minutes per day) and a decrease in musculoskeletal pain symptoms reported at three months follow-up.

The collective findings of these four reviews conclude that using standing desks has no effect on work performance, productivity or cognitive function in the short-term (Karakolis & Callaghan, 2014) or up to a year later (MacEwen et al., 2015). These reviews also concluded using standing desks had clear physiological benefits such as a reduction in musculoskeletal pain and reducing sitting time at work (Torbeyns et al., 2014; MacEwen et al., 2015). The next section outlines intervention studies investigating how standing desks affect cognition as well as the peripheral associated issues of standing desks use. These issues are alertness, postural variation, education and motor interference.

**Alertness and arousal.** There have been several studies that have investigated the impact of standing desks on alertness and arousal levels (Ebara et al., 2008; Hasegawa et al., 2001; Sliter & Yuan, 2014). This is an important preliminary step to discover if these desks affect cognitive performance, since performance will be adversely affected if individuals at standing desks are not attentive and responsive to tasks. When workers were asked to vary their posture between sitting and standing in Ebara et al’s (2008) study, there was no perceived subjective improvement in cognitive performance or mental alertness. However, when the participants’ heart rate variability was measured they found that in the sitting condition there was a significant sharp decline in arousal level 20 minutes after starting the
cognitive task, and thereby remained at this lower level (Ebara et al., 2008). Heart rate variability (HRV) is a measure of sympathetic nervous system activity which indicates arousal levels. When the participants utilised a standing desk that allowed variation between sitting and standing postures, their HRV was consistent for the duration of the task. This HRV result was an objective measure showing that there was a physiologically stable state of arousal and alertness when standing desks were utilised. This could be a more favourable physiological state for consistent work performance across the work day, as opposed to the sitting results which showed that workers become less alert and responsive after the first 30 minutes of the day when they begin their tasks, and then continue in this low state of arousal, possibly for the rest of their work day.

**Posture variation and micro-breaks.** One study found consistent work task performance when using a standing desk compared with using a traditional sitting desk. When participants remained seated there was a decline in performance but despite being a methodologically sound study, this finding was nonsignificant (Ebara et al., 2008) suggesting that performance was not impacted by sitting or standing conditions. These positive findings for standing desks could be explained by the micro-break effect, since standing desks inherently allow more opportunity for body movements than traditional sitting desks. Further research would need to isolate the impact of micro-breaks on these results, whereby scheduled breaks or specific movement prompts, independent from the sitting or standing condition are required.

A similar trend of consistent performance was seen when participants experienced posture variation, compared to sustained sitting or standing while doing a short-term, light repetitive task (Hasegawa, Inoue, Tsutsue & Kumashiro, 2001). These results suggest monotonous feelings of fatigue can be reduced if they are able to change between a sitting and standing posture as desired (Hasegawa et al., 2001) and ultimately their work performance will not be hindered. These findings should be interpreted with caution, since they are from a small cohort of eight participants only. Also it would be interesting to see if monotonous feelings of fatigue were still reduced in further research duplicating this study with a non-repetitive, cognitively-challenging task.

Another study which had stronger power with 180 participants, investigated four workstations – sitting, standing, walking and cycling (Sliter & Yuan, 2015). The results showed participants gained short-term, beneficial psychological effects, including higher satisfaction and arousal levels and lower stress and boredom with active workstations. These benefits were predominantly found for walking desks which could be a reflection of the higher energy effort required with walking compared to standing, and with less energy and coordination demands for walking than cycling. In a web-based work task, there was no change in performance (work volume achieved and accuracy scored) for the standing, walking or cycling desks (Sliter & Yuan, 2015). These findings for the walking desks may be explained by participants who were used to walking, so they found walking enjoyable and not
challenging thereby not changing their work performance. Whereas a more intensive condition like cycling may be more challenging, which could see both psychological effects and work performance decrease or remain unaltered. Confounding factors of this study were that task duration was only 35 minutes total and the sample population age (17-25 years) may not have been representative of the older, most probably less active office-based workforce population that is of primary concern (Sliter & Yuan, 2015). It is important to understand how postural variation and micro-breaks affect cognition and work performance, since such movement variation is inherently associated with the introduction and continued use of standing desks.

**Education and support for standing desks.** As with any workplace equipment changes, training and support are important so that users understand why and how best to use the equipment. One possibility explaining why some studies have found no change in their cognitive performance outcomes with a standing desk intervention, may be due to a lack of instruction or ergonomic educational support. A randomised controlled trial of 22 participants compared working at a sit-stand desk alone or sit-stand desk with the addition of office ergonomics training and education (Robertson, Ciriello & Garabet, 2013). The results showed greater work task accuracy in participants who had received standing desk and ergonomic training. As the cognitive difficulty level of the work task increased, the trained group seemed to adapt to the demand and maintain a consistently higher performance level compared to those who hadn’t received any training (Robertson et al., 2013). The control group in Robertson et al’s (2013) study were provided with a standing desk only with no instruction, support or training. Consequently all participants in this group chose not to stand at any point over the study duration (Robertson et al., 2013). This is understandable, if the participant was given no indication or explanation for why they would want to stand to work, or even how to use the new standing desk equipment. Therefore, there is a significant limitation to this study in that it did not test for the effect of the added ergonomic training intervention alongside sit-stand desks. Instead it only compared a sit-stand desk group with ergonomics training against a sitting desk group with no training. This study has significance to the wider research by showing that it is also important to provide educational support and training when implementing standing desks in the workplace. This will ensure the desks are actually used for their intended purpose and will yield the potential physiological and cognitive benefits to the worker.

**Motor task interference.** There has been some evidence suggesting standing desks may negatively impact cognitive performance, which could be due to interference caused by the greater motor demand associated with a standing desk. Lynch-Caris & Majeske (2014) investigated productivity with Fitt’s Tapping test - a computer input choice task involving cognitive decision-making processes followed by a physical response. In comparison to task times while sitting, their results showed a longer reaction time when the task was performed standing ($M = 1.16$ seconds) and walking ($M = 2.31$ seconds). This
indicates that these postures decreased task performance and the possible achievable volume of work. There was no significant productivity difference between the sitting and standing posture, indicating that participants could either sit or stand without adversely affecting productivity. But when the intensity level and movement complexity was increased in the walking condition, productivity decreased (Lynch-Caris & Majeske, 2014). This may be due to the dual-task interference paradigm, where using a computer while walking effects peoples’ balance so that more resources need to be diverted to maintaining balance rather than focusing on the mental task at hand (Lynch-Caris & Majeske, 2014). The authors used a robust and reliable outcome measure, but this study seemed to measure a short, acute task load. The total task duration was unreported, but from the mean reported results it appears to be approximately six minutes per participant to complete all trials at the three workstations. This is unlikely to capture the effects of a whole work day and the associated fatigue involved. There was also a small sample size of 11 participants and possibly some participant bias, since participants were all senior undergraduate ergonomics students. Similar studies have found comparable results in that cognitive performance did not change with standing or light-intensity walking and cycling (Bantoft et al., 2015; Commissaris et al., 2014).

A randomised, counterbalanced study of 50 participants aged 23 – 60 years, compared their ability to perform two cognitive tasks and a motor task while sitting, standing and walking (Ohlinger et al., 2011). Outcome measures tested attention, short-term memory, and simple motor skills within a single 75-minute session. The tasks were the Stroop test for selective attention (involving reading aloud a word list with altered colours), Auditory Consonant Trigram test for divided attention and short-term verbal-auditory memory (involving recalling letters while counting backwards) and Digital Finger-Tapping test (to assess fine motor control). No significant difference was found between sitting and standing for any of the three tasks. Only the motor task showed a decrease in performance between sitting and walking conditions (Ohlinger et al., 2011). These results indicate that working while walking or standing is unlikely to reduce a person’s ability to concentrate or accurately perform their work tasks. But working at a walking desk might affect tasks such as typing or answering a handset phone which involve a greater motor response, which would indirectly affect concentration and work volumes. From the results of these studies it appears there is little chance of motor interference to cognition occurring with the usual static standing postures assumed when working from a standing desk.

Comparable studies. There are two current studies which have a similar methodology to that proposed for this study. Bantoftet and colleagues (2015) conducted a randomised, counterbalanced study of 45 undergraduate students using cognitive performance measures based on the Wechsler scales. Their cognitive tasks were from the WAIS III and measured attention, processing speed, working memory and visual-motor speed and learning. Their results found no significant change to cognitive performance when participants’ were sitting, standing or walking at a low-intensity (Bantoftet et al., 2015).
Schraefel, Kenneth & Andersen (2012) conducted a crossover design, pilot study comparing sitting and standing work postures. Their testing was based on a computerised neurocognitive vital signs (CNSVS) test battery, which tested executive function, complex attention, cognitive flexibility, psychomotor speed, reaction time and processing speed, but excluded any tests of memory performance. The test results showed no difference in cognitive performance between sitting or standing, except for the task measuring complex attention which showed participants performance was improved when they were sitting (Schraefel et al., 2012).

Both studies were limited by short, overall intervention durations. In Bantofet et al.’s (2015) study the testing duration was one hour per week, across three weeks and Schraefel et al.’s (2012) study required only 30 minutes of sitting and standing, with a 10 minute washout period between. This is not a true representation of a typical working day and may not detect the effects of physical and mental fatigue that generally occur after eight consecutive hours of working. Additionally, neither study period allowed for someone to become used to the new working position and make appropriate adaptations. For these reasons it is difficult to make any definite conclusions about how these tests of cognition are affected by working from a standing or sitting desk and leave us none the wiser as to what posture may be the most appropriate for successful health interventions in the workplace.

Summary

To date, there has been an insubstantial amount of research on how the use of standing desks impact cognitive performance, including working memory. By accumulating more information about how standing desks affect our cognition and subsequent work performance, we will be able to ascertain the potential benefits of using standing desks in the workplace (MacEwen et al., 2015; Sliter & Yuan, 2015). The purpose of this study is to determine whether there are any effects on working memory performance while working at a standing desk. The study design will utilise a similar repeated measures, counterbalanced, crossover design to that used by Schraefel et al. (2012). This study will measure working memory performance with tasks from the Wechsler intelligence and memory scales (WAIS-IV and WMS-IV). The aims of this study are to eliminate a recurrent research limitation, by increasing the task duration so that a full day of cognitive tasks is included to simulate a full work day.
Chapter Two: Methods

Design

This was a randomised crossover design study with counterbalanced participants. In this research study, there were two “study days” whereupon each day ran from 9am to 4.30pm to simulate a real working day. Two break periods were provided, one at 11am for an hour’s duration and one at 2pm for 30 minutes. Participants could request additional breaks in between tasks if this was required. Participants were randomly allocated to either a sitting or standing condition for the first study day and then completed the remaining condition on the second study day. There was a washout period of 1 - 2 weeks before the second study day was completed. Efforts were made to test participants on the same day of the week that their first study day was conducted.

For each study day the participants were required to work through a set of 19 cognitive tasks and 4 work related tasks. This thesis outlines four of the 19 cognitive tasks that were used to assess working memory. The remaining 15 cognitive tasks (which are not part of this thesis), tested processing speed, attention, executive function and perceptual reasoning. The work related tasks included alphabetising, data entry, proofreading and transcription. This set of 23 tasks was repeated three times across the study day, and at the end of each set participants were asked to rate their fatigue level on a 1 – 10 categorised Visual Analogue Scale (VAS) (shown in Appendix F). Each set contained the same tasks in the same order of testing however, the content of each task was different, yet matched as well as could be for difficulty and consistency. An outline of how the study days were scheduled is shown in Figure 2.

At the start of the study day participants were asked to fill in a questionnaire detailing activities of the previous 24 hours (Appendix D). These included exercise, pain, tobacco and alcohol consumption, medication, sleep quality, fatigue levels, footwear and morning routine. At the end of the study day participants were requested to fill in a food diary of what they had eaten over the course of that day (Appendix E). For the subsequent second study day participants were requested to keep food intake and footwear as similar as possible to the first study day.
<table>
<thead>
<tr>
<th>Time</th>
<th>Study Day Layout</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00:00 a.m.</td>
<td>Testing Set #1</td>
<td>Task 4: Spatial span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Task 9: Letter-number sequencing</td>
</tr>
<tr>
<td>9:30:00 a.m.</td>
<td></td>
<td>Task 13: Arithmetic</td>
</tr>
<tr>
<td>10:00:00 a.m.</td>
<td>(Early) Lunch Break</td>
<td>Task 19: Visual reproduction</td>
</tr>
<tr>
<td>10:30:00 a.m.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:00:00 a.m.</td>
<td>Testing Set #2</td>
<td>Task 4: Spatial span</td>
</tr>
<tr>
<td>11:30:00 a.m.</td>
<td></td>
<td>Task 9: Letter-number sequencing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Task 13: Arithmetic</td>
</tr>
<tr>
<td>12:00:00 p.m.</td>
<td></td>
<td>Task 19: Visual reproduction</td>
</tr>
<tr>
<td>12:30:00 p.m.</td>
<td>Afternoon Tea Break</td>
<td></td>
</tr>
<tr>
<td>1:00:00 p.m.</td>
<td></td>
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</tr>
<tr>
<td>1:30:00 p.m.</td>
<td></td>
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</tr>
<tr>
<td>2:00:00 p.m.</td>
<td>Testing Set #3</td>
<td>Task 4: Spatial span</td>
</tr>
<tr>
<td>2:30:00 p.m.</td>
<td></td>
<td>Task 9: Letter-number sequencing</td>
</tr>
<tr>
<td>3:00:00 p.m.</td>
<td></td>
<td>Task 13: Arithmetic</td>
</tr>
<tr>
<td>3:30:00 p.m.</td>
<td></td>
<td>Task 19: Visual reproduction</td>
</tr>
<tr>
<td>4:00:00 p.m.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Study day outline.

Participants and Screening

Participants were recruited by using an online research participant recruitment site called researchstudies.co.nz and by word-of-mouth. Thirty participants were included in this study (14 females and 16 males) with an average age of 27.1 years ($SD = 5.11$) and 28.4 years ($SD = 8.29$) respectively.

Participants were required to register with researchstudies.co.nz and fill in a demographic and lifestyle questionnaire to establish their eligibility (Appendix C). Participants were excluded from the study if they had any known learning disabilities (such as dyslexia) and cognitive or physical pathologies, for example diagnosed chronic fatigue syndrome or a previous history of concussion or serious head injury. Any participants with musculoskeletal pathologies affecting the participants’ ability to stand for prolonged periods were also excluded from the study.

The recruitment website also contained the participant information sheet (Appendix A) outlining the details of the study, ethics approval information and the time required to participate in the study. All participants who had read the participant information sheet,
agreed to the study’s requirements and met the inclusion criteria, then provided written informed consent (Appendix B).

All participants were constantly monitored throughout each simulated working day to check for any adverse effects. Each participant received vouchers to the value of $200 as compensation for their time and effort.

Procedure

All testing was conducted at Unitec Institute of Technology, Mt Albert, Auckland, New Zealand. Before the first study day participants were required to attend a familiarisation session which lasted approximately an hour in duration. Participants were informed about the information to be collected during the study and each task was explained and demonstrated to them.

Participants were tested in a quiet, separate room and efforts were made to use a standing desk based on the participants’ height and comfort. The administration and scoring of the cognitive tasks was conducted on each participant individually and the same administrator was consistent for each participant through both study days. The administrator was one of five Master of Osteopathy students involved in the wider standing desk study.

On each study day, testing took approximately 90 - 120 minutes to complete each set. If a set took less than 120 minutes to complete then the participant was required to do additional work related tasks up to a total of 120 minutes. This was to ensure the duration of cognitive load was the same for each set across both study days.

Four tasks were used to measure working memory, two of which were adapted from the WAIS-IV: letter-number sequencing and arithmetic. The remaining two tasks were adapted from the WMS-IV: visual reproduction and spatial span.

The instructions that were given to the participant for each task are provided in Appendices H - K. The administrator either read these instructions aloud to the participant or paraphrased the same information. With all tasks participants were not informed by the administrator if their answers were correct or incorrect. Details of how task matching was done and how each outcome task was created is outlined under Appendix G.
Outcome measures

**Spatial span.** This task was adapted from the WMS-IV and measures the ability to recall and track in space. It is a visual working-memory task using the apparatus shown in Figure 3. Nine blocks were randomly arranged and permanently fixed to a base-board. The blocks were numbered 1 to 10 on one face and orientated towards the administrator, so that when the participant was positioned opposite the administrator they were unable to see the numbers written on the blocks.

The administrator pointed to a numbered sequence of blocks at the speed of one block per second. The participant was asked to remember the sequence locations of the blocks pointed to and reproduce the sequence by pointing to the blocks themselves. There were 10 items in each set and the sequences became progressively more difficult through the items. From a three–block sequence for Item One to a six-block sequence for Item Ten. The participant needed to get the entire sequence correct to gain one mark.

*Figure 3. Apparatus for Spatial Span (from administrator’s point of view).*
**Letter number sequencing.** This task was adapted from the WAIS-IV and measures attention, concentration and mental control. The administrator read aloud a series of letters and numbers to the participant, one digit/letter per second. The participant was asked to remember them, re-order them into the correct sequence and verbally repeat it back to the administrator. The correct order was numbers first in ascending numerical order and then letters in alphabetical order. All given numbers were between 1 and 9, and letters were between A and F.


The participant had as much time as needed to recall the order. The participant was instructed that the administrator would only give the sequence once. There were 10 items in this task and sequences became progressively more difficult with more letters or numbers added to subsequent item sequences. When the participant gave three consecutive incorrect answers the task ceased. The participant was required to get the entire sequence correct to score one mark.

**Arithmetic.** This task was adapted from the WAIS-IV and measures concentration while manipulating mathematical problems. This is a verbal working memory task where the participant was asked to solve an arithmetic problem. The administrator read aloud an equation in story format. The participant was asked to listen and remember the numbers and mathematical functions. So they could solve the equation and then verbally report their answer to the administrator.

For example:

*A dog has three biscuits in his bowl inside and four biscuits in another bowl outside. The neighbours’ cat eats half the biscuits in the outside bowl. How many biscuits are left?*

In this item the equation to solve was: $3 + (4/2) = 5$. For the correct answer, the participant would need to reply “five” or “five biscuits”. The participant had as much time as needed to give their answer. The participant was instructed that the administrator would only give the arithmetic problem once. There were 10 problems in a set and the problems
progressed in difficulty. When the participant gave three consecutive incorrect answers the task ceased. The participant was required to get the answer correct to score one mark.

**Visual reproduction.** This task was adapted from the WMS-IV and measures the ability to recall and reproduce visual patterns. The images were based on the Rey Osterrieth Complex Figure, which is a widely used neuropsychological assessment measure developed in the 1940s. It is used to assess visuospatial constructional ability and visual memory (Shin, Park, Park, Seol & Kwon, 2006). The participant was instructed to look at and memorise an abstract image (Figure 4) for 20 seconds. The image was then removed from sight and the participant was then asked to reproduce the image with pen and paper within 40 seconds. There were seven images per set, with equivalent difficulty across all images in the set. Each reproduction could score a maximum of 10 points if all elements were reproduced with correct orientation, location, proportion, shape, quantity and opacity. Half marks were also scored if an element was partially correct, but not exactly the same as in the original image (see Appendix L. Administrators marking guide for Visual reproduction task).

![Figure 4. Example item of abstract image for Visual Reproduction.](image)

**Statistical Analyses**

Data were collated using Microsoft Excel, and then analysed using SPSS version 19 (SPSS and IBM company, Chicago IL). Variables were explored for assumptions of normality by analysing the values for skewness and kurtosis with their standard errors and completing a Shapiro-Wilk test. Two-way repeated measure ANOVAs were used to identify main effects of Condition and Time of Day on each measure. Mauchley’s tests for sphericity were conducted, and Greenhouse-Geisser corrections applied when sphericity was violated.
Chapter Three: Results

Effects for all variables were analysed using repeated-measures ANOVAs with Condition (Sitting and Standing) and Time of Day (morning, midday and afternoon) as the within-subjects factors.

Spatial Span

For the Spatial span variable there was a main effect of Condition, $F(1,29) = 6.72, p = 0.015$, revealing a significant increase in correct scores (%) for Standing ($M = 84.90, SE = 1.86$) compared to Sitting ($M = 81.0, SE = 2.30$), $p = 0.015$. There was no effect of Time of Day, $F(2,58) = 0.91, p = 0.393$, nor was there an interaction between Condition and Time of Day, $F(2,58) = 1.71, p = 0.190$ (see Figure 5).

![Figure 5. Percentage correct scores for Spatial span task, during Standing and Sitting conditions at three times across the day (error bars represent standard error of the mean).](image)

Letter Number Sequencing

For Letter number sequencing, no main effect was observed for Condition, $F(1,29) = 2.37, p = 0.135$, and there was no evidence of an interaction between Time of Day and Condition, $F(2,58) = 97.22, p = 0.591$. There was, however, a significant main effect for Time
of Day, $F(2,58) = 4.36$, $p = 0.017$. Pairwise analysis revealed that there was a significant
difference between Morning ($M = 68.17$, $SE = 2.70$) and Midday ($M = 75.17$, $SE = 3.24$), $p =
0.046$, a trend toward significance between Midday and Afternoon ($M = 68.00$, $SE = 3.17$), $p =
0.066$, but no difference between Morning and Afternoon, $p > 0.99$ (see Figure 6).

Figure 6. Percentage correct scores for Letter number sequencing task, during Standing and Sitting
conditions at three times across the day (error bars represent standard error of the mean).

Arithmetic

For the variable Arithmetic, no main effect was observed for Condition, $F(1,29) =
0.34$, $p = 0.568$, and there was no evidence of an interaction between Time of Day and
Condition, $F(2,58) = 1.14$, $p = 0.328$. There was, however, a trend toward a significant main
effect for Time of Day, $F(2,58) = 2.96$, $p = 0.060$. Although the pairwise analysis revealed no
significant differences between any of the three Time of Day variables; Morning ($M = 88.96$, $SE =
2.70$), Midday ($M = 84.79$, $SE = 2.20$), Afternoon ($M = 84.79$, $SE = 2.35$), Morning
showed the highest percentage correct compared to both Midday and Afternoon (see Figure
7).
Visual Reproduction

For the Visual reproduction variable there was no main effect of Condition, $F(1,29) = 0.06$, $p = 0.802$, and no interaction between Condition and Time of Day, $F(2,58) = 0.47$, $p = 0.625$. Again there was a significant effect of Time of Day, $F(2,58) = 17.40$, $p < 0.001$.

Pairwise comparisons revealed a significant decrease in percentage scores across the whole day, between Morning ($M = 62.21$, $SE = 2.67$) and Midday ($M = 59.49$, $SE = 2.70$), $p = 0.021$, Midday and Afternoon ($M = 56.56$, $SE = 2.69$), $p < 0.001$, and Morning and Afternoon, $p = 0.010$ (see Figure 8).
Fatigue

For the variable Fatigue, there was no main effect of Condition, $F(1,27) = 1.39, p = 0.249$, but there was a main effect of Time of Day, $F(2,54) = 25.60, p < 0.001$. Pairwise analyses revealed a significant increase in Fatigue (more fatigue) between Morning ($M = 3.55, SE = 0.29$) and Midday ($M = 4.47, SE = 0.27$), $p = 0.003$, and between Morning and Afternoon ($M = 5.52, SE = 0.28$), $p < 0.001$, as well as between Midday and Afternoon, $p <$
There was no interaction between Condition and Time of Day, $F(2,54) = 1.17, p = 0.318$ (see Figure 9).

Figure 9. Mean Fatigue Score during Sitting and Standing conditions at three times across the day (error bars represent standard error of the mean).
Chapter Four: Discussion

The results of this study demonstrate that for three (Arithmetic, Letter number sequencing and Visual reproduction) of the four measures investigated here there was no difference to an individual’s working memory abilities when working from a sitting or standing desk. The results of the fourth measure (Spatial span) showed that working at a standing desk yielded improved working memory. This result was a small, but statistically significant improvement in the percentage of correct scores achieved when the participant stood, compared to sitting (4.8%, $p = 0.015$). In the wider study four of the 19 tasks showed cognitive performance was improved when standing, as it was in the Spatial span measure reported here (Appendix M).

Interestingly, in the three tasks that did not show an effect of Condition, all showed an effect of Time of Day (although the Arithmetic task showed only a trend toward significance). The Letter number sequencing task showed that participants’ performance improved from the morning testing and peaked at midday before decreasing in the afternoon. This change in performance over the day may be due to a learning effect as the participants became more efficient when they performed the task for the second time at midday. However, these gains were lost by the afternoon when participants had done 5.5 hours of work and it is possible fatigue effects may have been setting in. This time of day trend in performance makes sense, since the Letter number sequencing task is a challenging and novel task that most participants had not encountered before and it is unlike usual, everyday tasks.

The Arithmetic task results showed a trend toward better performance in the morning, suggesting this aspect of working memory was not greatly altered by sitting or standing, but was done best first thing.

The results for the Visual reproduction task showed that performance scores decreased progressively over the day from morning to midday, and again to afternoon. This could suggest fatigue, or possibly boredom, had an impact on the participants’ ability to perform this task. This coincides with the Fatigue results that showed a significant increase in mean subjective fatigue at every time point over the day ($p < 0.001$), which was a clinically important change between the morning and afternoon (an increase of 55% on a 1 – 10 categorised VAS). This increase in fatigue over a 7.5-hour working day is to be expected and would be a normal characteristic of anyone’s work day. The Fatigue results showed that there was no significant interaction of Condition or Condition and Time of day. This indicates participant fatigue level increased in the same manner regardless of whether participants were working at a sitting or standing desk.

Across the research area there is a wide variety of study designs and cognitive outcome measures, which makes it difficult to directly compare our results with any similar studies. Robertson and colleagues (2013) conducted a study with an intervention duration of
7-hour testing days over a 15 day period however, the standing requirement was only 35 minutes per day and then 140 minutes per day in the last six days of the study. Khatri et al. (2001) is the only known study utilising a similar Visual reproduction outcome measure. They used it to assess the effects of exercise on older adults with depression and found a significant improvement in Visual reproduction scores in the exercise intervention group. Another recent randomised controlled trial had the same aim as this study, except they included a treadmill desk alongside the sit and stand desks to investigate how they impacted cognitive function (Bantoft et al., 2015). They used the same Letter number sequencing task as a measure and found small effect sizes and no significant difference between sitting, standing or walking (Bantoft et al., 2015). To date, a study by Schraefel and colleagues (2012) had the most similar study design as this study (except their intervention duration was only thirty minutes for each sitting or standing condition, separated by a ten minute washout period). They investigated six cognitive domains with five cognitive tasks, however, working memory was not an included domain. All domains showed no significant difference between sitting or standing, except the Complex attention domain, which had slightly higher scores in the sitting condition (Schraefel et al., 2012). Similar findings were found in our wider standing desk study where 15 of the 19 cognitive measures showed no difference in cognitive performance when sitting or standing. Furthermore none of the measures showed that performance was better while sitting down to work compared to working at a standing desk (Appendix M).

The findings from the Arithmetic, Letter number sequencing and Visual reproduction measures are consistent with multiple other studies that found no difference in cognitive performance when sitting or standing (Bantoft et al., 2015; McEwen et al., 2015; Ohlinger et al., 2011; Schraefel et al., 2012; Torbeys et al., 2014). There has been no research to date showing any negative effects of standing desks on working memory function. The closest negative finding was reported by Commissaris et al. (2014) when participants were using a cycling workstation at 40% heart rate reserve, and the N-back test was used as a measure of working memory performance. Overall there is still a clear lack of strong studies on how standing desks impact cognitive abilities (McEwen et al., 2015; Schraefel et al., 2012; Shrestha et al., 2015).

A strength of this study was its randomised, crossover, counterbalanced, repeated measures design. An inherent limitation of crossover study designs, however, is the possibility of carryover effects, which could impact the data collected on the second testing day. This study minimised these effects by including a washout period between testing days, which was set at a minimum of seven days at least, or up to 14 days maximum. Participants were also required to attend a pre-study familiarisation session to reduce learning effects on the first day of testing. To minimise the possibility of carryover effects between the three testing sets, substantial efforts were made to ensure the cognitive tasks in each set had similar, but different content. Likewise, efforts were made to equally match the tasks for content and
difficulty between the study days (the details of how this was achieved are described in Appendix G).

The outcome measures used in this study for cognitive performance were based on the same tests used in the Wechsler adult intelligence scales and have been well studied and validated. Where many previous studies on standing desks have only used one or a few cognitive tests at most, this study was part of a wider study with a comprehensive range of 19 cognitive tasks measuring multiple functions of cognition (see Appendix M for full Standing Desk Study results). This study on working memory used four different tasks to measure two of the main components of working memory performance – the visuospatial and verbal-auditory stores. Alternatively many standing desk studies used their own work-based tasks to measure performance at a standing desk, which may be generalizable to those tasks performed in a typical office environment, but they can have low reproducibility and are not validated measures. The measures here were further adapted from those in the Wechsler scales and each task was firstly pilot tested to verify the level of difficulty, so that no task was too easy or unachievable. Future research or replication of this study, however, would benefit from each cognitive measure being assessed for reliability and validity.

Within each of the four measures used in this study there are specific methodological improvements that could be made. The administration of Letter number sequencing and Spatial span could be improved on the timing of each item sequence as it was presented to the participant. It was observed that these two tasks were more vulnerable to test administrator pauses or intonation changes, which could have a significant influence on the participant’s ability to recall the sequence. One way this could be improved for Letter number sequencing is to use an audio recording of the item sequences, which would give consistent intonation and speed, whilst also eliminating the possibility of context bias within the administrator-participant interaction. An example of how a context bias may occur, is the tendency of participants to score higher if the administrator is the same ethnicity, or woman tend to score higher if there is a female administrator (Reynolds & Suzuki, 2013). Similarly, the Arithmetic task could be re-evaluated for testing bias, where the content of each item question may have had a sociocultural context that inadvertently measured differences caused by cultural experiences or social factors. An example of this is rural and urban context, when a person from the city may perform poorly on questions that involve farming content.

The participants’ performance of the Visual reproduction task in particular decreased as the study day progressed which fits with the increased fatigue ratings over the day, thus demonstrating the unfavourable effects of fatigue on participant performance. It is also possible test administrator fatigue would have increased over the course of the study day. The participant’s performance could have been unintentionally influenced by the administrator’s external behavioural cues, such as yawning or sighing. Although, this is an inherent characteristic of many intervention studies and it would be difficult to eliminate this
influence as it would involve altering the study design so that there was no interpersonal administration of the cognitive tasks.

For future research a specific aspect of our methodology that could be expanded on was the fatigue measure. Each participant was asked to rate their level of fatigue at the end of each of the three blocks of testing on both study days. A few participants were confused by this instruction and asked for clarification if they were to rate their physical fatigue or mental fatigue. They were then instructed to rate their overall fatigue. However, for future researchers specifically interested in the fatigue variable of cognitive performance, they may need to clarify participant instructions or include both physical and mental subjective ratings of fatigue. Physical and mental fatigue are different symptoms that occur independently, but often one leads to the other or both happen arise at the same time (Nordqvist, 2015). This is especially applicable for future research of standing desks because a recurrent argument presented against the use of standing desks, is that they may be associated with an increase in fatigue. This was not the case according to the results of our study, as sitting and standing showed a similar increase in fatigue as the day progressed, and there was no evidence fatigue was greater due to standing desk use. Further research into standing desk use and fatigue will be beneficial to confirm this finding.

The sample population of this study had strong external validity in regards to the variation of participant characteristics such as education, occupation and existing estimated activity level. This variation makes the study results generalizable to a typical office workplace population. Similarly each study day was 7.5 hours in duration, which is comparable to a typical work day duration. Many standing desk studies have short durations which do not reflect a full work day and therefore will not incorporate the effects of cognitive loading or fatigue across the whole day. The participant age range was 20 - 49 years which generally represents the age range of an office-based workforce population, where such workers may benefit from the introduction of standing desks. This also provides generalisability of our results to a wider work force population.

Other possible research that would expand on this study’s findings could involve a wider age range of participants. Specifically, selecting a sample population within the 30-65 years age group, since this proportion of the workforce has had little investigation so far. This may yield different results because as an older age group they tend to be less adaptable biomechanically and cognitively than younger adults (Kosslyn et al., 2014). By changing their routine work posture to standing, there may be a detrimental effect seen on cognition and an increase in musculoskeletal complaints.

Alternatively this age group is often less physically active (Caspersen, Pereira & Curran, 2000), so introducing a standing desk may reveal a greater change in their cognitive performance compared with individuals who are already physically active. It could be interesting to further analyse how our results correlate with how physically active each
participant was pre-study (this study collected unanalysed data on subjectively rated sedentary, light, moderate or heavy activity level and self-estimated average hours per day spent sitting at work and home). This further research could test the hypothesis that there are greater improvements in cognitive performance in individuals who are primarily sedentary at baseline.

Further research could be carried out around tasks utilising cognitive function as tested by the Spatial span task of this study. The findings of this study indicated a small, significant improvement in Spatial span performance when working from a standing desk rather than a sitting desk. Further research could elaborate on this result and reveal the specific aspects of working memory function that standing desks can improve. Specifically the Spatial span task corresponds to the visuospatial component of working memory function (Baddeley, 2001). This is especially pertinent for workers whose job tasks involve a lot of visuospatial recall such as spatial designers, graphic designers, landscape gardeners, city planners, architects, radiographers and sonographers. Should this positive finding be further confirmed by future research, these workers would be better informed of the optimal position for their cognition and work performance.

The results from this study have given an indication of the acute effects of using standing desks on working memory performance, but it would be interesting to know the effects of standing on working memory and other aspects of cognition over a longer time period. The condition duration could be increased to a programme of several weeks or months of consecutive, full work days standing compared to sitting. Additionally, it would be interesting to conduct longitudinal studies measuring the effects of standing desk use up to a year or more. This is especially pertinent since there are some suggestionst workplace use of standing desks is a passing fad (Buckley et al., 2015) and one small study found standing desks were not utilised between six months to one year after introduction (as cited in Karakolis et al., 2014, p. 799). Most of the current research investigating standing desks covers an immediate to short-term time frame, when the novelty effect is strongest and may exert influence on standing desk use and results. This frequently studied time frame is most likely due to the inherent pragmatic considerations of such studies. Since a longer experimental duration requires a significant time commitment from participants and therefore requires greater funding resources and has a greater chance of participant drop-outs. Despite these issues there is a need for more research and information on the physical and cognitive benefits of ongoing, continued use of standing desks.

Overall there is a need for further research around the rationale of introducing standing desks to a mostly sedentary population. This research is needed to ascertain the mechanism of sitting causing the predominant trend, where a high amount of daily sitting time is predictive of a higher mortality risk, even when such individuals achieve the recommended amount of physical activity per day (Biswas et al., 2015; Dunstan et al., 2012; Healy et al., 2008; Katzmarzyk et al., 2009; Stamatakis et al., 2011; Wijndaele et al., 2009). It is possible
this mechanism is due to postural biomechanical factors of sitting or for total energy balance metabolism reasons. Or it may be due to confounding environmental factors, for example, sitting at work can also be accompanied by a higher level of stress and sitting during leisure time can also be accompanied by snacking (Pulsford et al., 2015).

The results of this study have significant implications for the office-based workforce in NZ, specifically for those that have a predominantly sedentary workstation. It is especially relevant to those workers who may already have health risk factors, such as metabolic syndrome, diabetes, obesity and hypertension. These individuals can be reassured by the results of this study which show standing desks can be implemented without concern about any negative effects on their cognitive work performance, whilst utilising the potential physiological benefits as reported in the wider literature (Healy et al., 2015; Stephens et al., 2011).

Our results are also relevant for employers’ considerations of the work environment and primary health clinicians delivering best healthcare advice to their patients.

**Conclusion**

This study appears to be the first to comprehensively assess how working memory is affected by standing desk use. This was achieved by using four working memory specific tasks (based on the long-established, reliable and valid Wechsler intelligence and memory scales), and by utilising a robust study design with an intervention duration comparable to a typical work day period.

The results of the Spatial span task showed a small but significant increase in performance when working at a standing desk compared to a sitting desk. The other three measures found no significant impact on working memory performance when sitting or standing. Three of the cognitive measures showed a significant Time of day effect for both sitting and standing desks, and there was a significant increase in fatigue levels over the day regardless of whether a sitting or standing desk was used. Which suggests an individual’s fatigue builds over the course of a 7.5-hour work day, as would be expected. However, individuals can be confident that this fatigue effect is unchanged whether they use a sitting or standing desk to work. Furthermore, the results of this study show no evidence that working memory function is negatively impacted by using a standing desk, and may even be improved when conducting work tasks requiring visuospatial working memory.

The results from this study are consistent with the current literature on standing desks, which suggests that working from a standing desk has no known negative impact on an individual’s cognitive performance. This allows an opportunity to consider implementing standing desks in the workplace for their physical benefits. Our results are informative for workers or employers who can confidently introduce standing desks and be assured there will
be no detrimental impact to the amount or quality of work completed in a standard working day. Thereby allowing them to maximise the health benefits of standing while also achieving company targets.
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Chapter Six: Appendices

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Appendix A. Participant Information Sheet

Information for participants

Research Project Title:

To what extent does working from a standing desk influence cognitive performance?

Synopsis of project

Recent evidence shows that a high level of sedentary behaviour, such as prolonged sitting, is negatively correlated with an increased metabolic risk score, risk of cardiovascular events, and all-cause mortality.

The introduction of standing desks into the workplace offers a potential solution to the inactivity problem. Given that desks are typically workplace tools, it is logical to enquire about the effects of a standing desk on cognitive performance.

The goal of this project is to evaluate the effects of working from a standing desk compared with a seated desk on cognitive performance during a simulated working day.

What we are doing

To find out more we are asking all participants to perform 7.5 hours of tasks that emulate a typical office working day (e.g., transcription, data entry...) and various validated cognitive performance measures (e.g., solving puzzles, recalling numbers). All participants will attend two days; one day performed from a normal sitting desk, and one from a standing desk. Scheduled breaks are included, and standing desk participants are allowed to sit when they feel they need to (but are “encouraged” to stand as much as comfortable).

Participants will be asked to wear comfortable footwear, to match their dietary intake (i.e., coffee, sugars), and to be mindful of activities that may affect cognition (e.g., exercise, late night, alcohol) for both days.

To participate in this study you will need to be fluent in English, between 18 and 50 years of age, have normal colour vision, and will need to feel confident in your ability to stand comfortably for extended periods of time. You will not be able to participate if you have 1) musculoskeletal pathologies preventing or influencing your ability to stand for prolonged periods, and 2) cognitive pathologies, such as chronic fatigue or any previous serious head injury, or be taking medications, which may affect concentration and cognitive performance.
What it will mean for you

Involvement in this study will require you to attend a familiarisation session of approximately 90 minutes at the Unitec Mount Albert campus. During this session you will get to see all the tasks that will be performed during the study, and will be given the opportunity to ask questions about the study before choosing to enrol.

If you choose to enrol, you will attend a full day (9:00 am to 4:30 pm) at the Unitec Mount Albert campus where you will be allocated to either a standing or sitting desk. You will be provided with numerous tasks to perform throughout the day, and will be guided through all tasks by a researcher. All tasks can be completed from the desk, and all tasks involve varying amount of cognitive load (i.e., they are all thinking tasks). There are three break periods throughout the day, and standing desk participants are allowed to sit when needed.

You will need to also attend a second day, approximately one week later, where you will repeat the day using a different desk (everyone will do one day from each desk). Upon completion of the second day you will be compensated with $200 worth of vouchers (either fuel or WestField) for your time. You may also be sent an overview of the findings upon completion of data analysis and interpretation.

If you agree to participate, you will be asked to sign a consent form. This does not stop you from changing your mind if you wish to withdraw from the project. Your parent/guardian can also ask for you to be withdrawn.

Your name and information that may identify you will be kept completely confidential. All information collected from you will be stored on a password protected file and only you and the researchers involved will have access to this information.

Please contact us if you need more information about the project. At any time if you have any concerns about the research project you can contact the principal investigators:

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lpatston@unitec.ac.nz

Jamie Mannion
021673832
(09)8154321#8475
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UREC REGISTRATION NUMBER: 2014-1085
This study has been approved by the UNITEC Research Ethics Committee from 25.9.14 to 25.9.17. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 6162. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Appendix B. Participant Consent Form

To what extent does working from a standing desk influence cognitive performance

I have had the research project explained to me and I have read and understand the information sheet given to me.

I understand that I don’t have to be part of this if I don’t want to and I may withdraw at any time prior to the completion of the research project.

I understand that everything I say is confidential and none of the information I give will identify me and that the only persons who will know what I have said will be the researchers and their supervisor. I also understand that all the information that I give will be stored securely on a computer at Unitec for a period of 5 years.

I understand that I can see the finished research document.

I have had time to consider everything and I give my consent to be a part of this project.

Participant Signature: ……………………………………………………… Date: ……………………………

Participant Name:………………………………………………………………………………………………………………

Project Researcher: ……………………………………………………… Date: ……………………………

Project Researcher Name:……………………………………………………………………………………………………

UREC REGISTRATION NUMBER: 2014-1085
This study has been approved by the UNITEC Research Ethics Committee from 25.9.14 to 25.9.17. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 6162. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Appendix C. Pre-Study Participant Demographic Questionnaire

Participant Eligibility and Demographic Questionnaire

The following questions assess your eligibility to take part in the study:

Is English your first language? ☐ Yes ☐ No

If not, can you describe your proficiency in English? Include the other languages you speak and how old you were when you first became fluent in English.

*(many of the tasks involved in the study require proficient fluency in English)*

Have you had, or do you have, any injuries or conditions that hamper your ability to stand for prolonged periods? ☐ Yes ☐ No

*(on one day of the study you will be required to stand for long periods of time – 1.5 hours)*

Do you have, or have you had, any of the following:

a. Serious head injuries (including concussions) ☐ Yes ☐ No

b. Other issues affecting your ability to concentrate? ☐ Yes ☐ No

c. Medication affecting your ability to concentrate? ☐ Yes ☐ No

*(many of the tasks involved in the study require sustained concentration)*

Are you clinically colour-blind? ☐ Yes ☐ No

*(some of the tasks involve discriminating between different colours – i.e., red, blue, green)*

If you answered “Yes” to any of these then we regret to say you are not eligible to participate in the study, but we thank you for your interest. Depending on your answer to the first question regarding English as a first language, we may be in touch with you to discuss possible participation.

If your answer to all of the above was “No”, please complete the following demographic question:
First Name: ___________________________ Gender: ___________________________
Surname: ___________________________ Date of Birth: ___________________________
Height: _____ Weight: _____ Ethnicity: ___________________________
Home phone: ___________________________ Work phone: ___________________________
Email Address: __________________________________________________________________
Postal Address: __________________________________________________________________

Do you speak any other languages apart from English? ☐ Yes ☐ No
If yes, please specify:

What is your usual occupation?

What (if any) regular physical activity do you maintain (include any sports you play)?

What (if any) are your other hobbies (e.g., music, computer games, puzzles, reading)?

How would you describe the level of physical activity at your work:
☐ Sedentary (brief standing and walking required)
☐ Light (frequent standing and walking required)
☐ Moderate (required to lift small loads / some bending, or frequent walking)
☐ Heavy (frequent lifting required, often over 10 kgs, or lots of walking)
☐ Very heavy (consistent lifting, often over 20 kgs, or frequent running)

Do you currently use a standing desk? ☐ Yes ☐ No

How many hours would you spend sitting in an average day at work?
How many hours would you spend sitting in an average day at home?

Have you sustained any injuries which affect your ability to work? ☐ Yes ☐ No

Please provide details:

Do you experience pain on a regular or sustained basis? ☐ Yes ☐ No

Please provide details (including intensity of pain):

What academic qualifications do you hold and/or are currently studying toward? Include school qualifications.

Have you participated in any cognitive testing before? ☐ Yes ☐ No

Please provide details:
Appendix D. Participant Log Completed at the Start of Both Study Days

Set 1 – Participant Log

1. What day of the week is it today? Circle one.

Monday  Tuesday  Wednesday  Thursday  Friday  Saturday  Sunday

2. In the last 24 hours, what exercise have you engaged in? Include the exercise type, frequency and intensity.

3. Do you currently have any injuries? If so, please describe.

4. Are you currently on any medication? If so, please describe?

5. Do you smoke? If so, how many cigarettes have you had in the last 24 hours

☐ I do not smoke
☐ 1-5
☐ 6-10
☐ 10+

6. Have you taken other substances in the last 24 hours? If so, please describe?
7. How many hours sleep have you had in the last 24 hours?

☐ No sleep
☐ 1-4 hours
☐ 5-6 hours
☐ 7-8 hours
☐ 9+ hours

8. If you were to rate your quality of sleep in the last 24 hours, what score would you give it?

0 1 2 3 4 5 6 7 8 9 10
Poor Excellent

9. How are you feeling today?

10. Please comment on fatigue, energy, pain, discomfort, feeling unwell or rundown, have any significant life events occurred recently?

11. How much alcohol have you consumed in the last 24 hours?

☐ 1-2 drinks
☐ 3-4 drinks
☐ 5-6 drinks
☐ 7+ drinks

12. What shoes did you wear today?
(Please ensure that you wear the same shoes each time you engage in the study)

13. Has your morning routine changed in the last 24 hours? If so, please describe.
Appendix E. Participant Log Completed at the End of Both Study Days

Set 3 – Nutritional Intake Form

Nutritional Log for Standing Desk Participants

1. Please provide a list of drinks you have had today (include coffee, tea, water, juices, and any energy drinks or supplement drinks. If nil, please state)

2. Provide a detailed list of food (and quantity where possible) you have consumed today (including snacks)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakfast</td>
<td></td>
</tr>
<tr>
<td>Morning Tea</td>
<td></td>
</tr>
<tr>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>Afternoon Tea</td>
<td></td>
</tr>
</tbody>
</table>

3. Provide a list of any supplements consumed today (Example: Multivitamin, fish oil, protein powder. If Nil, please state)
Appendix F. Example of Fatigue Scale Completed at the End of Each Testing Session

Set 1 – Level of Fatigue Scale

Circle the level of fatigue or tiredness you are feeling right now.

Where 0 = no fatigue or tiredness at all
And 10 = the worst fatigue or tiredness imaginable

0  1  2  3  4  5  6  7  8  9  10
Appendix G. Cognitive Task Development and Matching

Each task was rearranged or altered slightly to create tasks with different content but a matched level of difficulty between each study day. Details of how task matching was done and how each outcome task was developed is outlined below.

All tasks were checked with pilot testing before participant recruitment began. This involved repeated testing of each task on staff and students who were involved in the study, as well as some external volunteers. After this the complete set of tasks were tested and timed under study conditions on a volunteer matching the screening criteria. The volunteer was then excluded from future participation in the study.

Spatial span, Letter number sequencing and Arithmetic all had items that got progressively more difficult as the task continued. They all had a discontinue rule, where three incorrect, consecutive answers resulted in termination of the task for that set. Each item was administered to the participant once and no repeats were allowed. Visual reproduction did not get more difficult as the task continued, each item was designed at random. Any participant’s perception of greater or lesser difficulty was unintentional.

Spatial span

There were 10 items in each set and the block sequence progressed from a three-block sequence to a six-block sequence. The blocks were numbered 1 – 9 and the block sequence for each item was created by random number generation. These sequences were then checked with the block apparatus (see photo of apparatus in Figure 3) to ensure they were not too simple. In items 6 and 9 one block in the sequence was duplicated with two or three blocks in between.

Matching for the second study day was achieved by using the same block sequence but reversing the order. An example of how Set 1 and Set 4 items matched each other is shown in Figure 10.

<table>
<thead>
<tr>
<th>Set 1</th>
<th>Set 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 5  8  4</td>
<td>1. 4  8  5</td>
</tr>
<tr>
<td>2. 3  2  5</td>
<td>2. 5  2  3</td>
</tr>
<tr>
<td>3. 5  2  3  4</td>
<td>3. 4  3  2  5</td>
</tr>
<tr>
<td>4. 7  3  1  5</td>
<td>4. 5  1  3  7</td>
</tr>
<tr>
<td>5. 5  6  3  7  8</td>
<td>5. 8  7  3  6  5</td>
</tr>
<tr>
<td>6. 9  2  7  3  2</td>
<td>6. 2  3  7  2  9</td>
</tr>
<tr>
<td>7. 6  8  1  2  9</td>
<td>7. 9  2  1  8  6</td>
</tr>
<tr>
<td>8. 9  7  3  5  4  2</td>
<td>8. 2  4  5  3  7  9</td>
</tr>
<tr>
<td>9. 3  8  1  2  7  8</td>
<td>9. 8  7  2  1  8  3</td>
</tr>
<tr>
<td>10. 2  9  7  3  9  6</td>
<td>10. 6  9  2  3  4  7</td>
</tr>
</tbody>
</table>

*Figure 10. Example of Set 1 and matching Set 4 items for the second study day.*
Letter number sequencing

There were 10 items in each set, progressing in difficulty from a four letter/number sequence to a six letter/number sequence. The letters and numbers were placed according to the template structure shown in Figure 10. The letters and numbers used were 1 – 9 and A – F and these were randomly selected without replacement.

The template structure for the sequences (as shown in Figure 11) was based on a progression from four to six letter/numbers. Difficulty of the sequences as the items progressed was based on the pilot testing observation that people find numbers easier to order than letters. Also people found it more difficult remembering and manipulating letters and numbers which are mixed than two numbers or two letters next to each other. For example remembering and reordering D 2 B 5 in memory is more difficult than D B 2 5 (the correct answer in this example would be reported back to the administrator verbally as 2 5 B D).

Task matching for the second study day was achieved by using different letters and numbers but consecutive digits selected (e.g., 8 replaced with 9 or 7. Four replaced with 3 or 5. B replaced with C or A etc.). It was decided to replace numbers and letters in this way to keep the difficulty level as similar as possible between the two study days. It was found that matching to the second study day could not be achieved by just reversing each sequence, because the letter/number template structure would change. Also it was observed that people found it easier to remember and manipulate the lower numbers such as one to three, compared to the higher numbers such as seven to nine. Similarly people seemed to find it easier to remember and manipulate the first letters A to C compared to the later letters D to F. This is most likely due to familiarity and the way people learn letters and numbers. It was found that matching to the second study day could not be achieved by reversing each item, because the letter/number template structure would change.

<table>
<thead>
<tr>
<th>Item</th>
<th>Structure</th>
<th>Sequence</th>
<th>Correct Answer</th>
<th>Sequence</th>
<th>Correct Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N L L N</td>
<td>5 C F 2</td>
<td>2 5 C F</td>
<td>4 B E 1</td>
<td>1 4 B E</td>
</tr>
<tr>
<td>2</td>
<td>L N N L</td>
<td>D 7 3 A</td>
<td>3 7 A D</td>
<td>C 6 2 B</td>
<td>2 6 B C</td>
</tr>
<tr>
<td>3</td>
<td>L N L N</td>
<td>E 9 B 3</td>
<td>3 9 B E</td>
<td>D 8 A 2</td>
<td>2 8 A D</td>
</tr>
<tr>
<td>4</td>
<td>L L N L</td>
<td>F D 6 A</td>
<td>6 A D F</td>
<td>E C 5 B</td>
<td>5 B C E</td>
</tr>
<tr>
<td>5</td>
<td>N L L N N</td>
<td>5 F A 3</td>
<td>1 3 5 A F 2</td>
<td>6 E B 4</td>
<td>2 4 6 B E</td>
</tr>
<tr>
<td>6</td>
<td>L N N L N</td>
<td>C 6 B B 5</td>
<td>5 6 B C</td>
<td>D 5 7 A 4</td>
<td>4 5 7 A D</td>
</tr>
<tr>
<td>7</td>
<td>L N L N N</td>
<td>A 2 F 7 4</td>
<td>2 4 7 A F</td>
<td>B 1 E 8 5</td>
<td>1 5 8 B E</td>
</tr>
<tr>
<td>8</td>
<td>N L N L N</td>
<td>8 C 4 E 5</td>
<td>4 5 8 C E</td>
<td>9 B 3 F 6</td>
<td>3 6 9 B F</td>
</tr>
<tr>
<td>9</td>
<td>L L N L N L</td>
<td>D F 9 B 4 A</td>
<td>4 9 A B D F</td>
<td>C E 8 A 3 B</td>
<td>3 8 A B C E</td>
</tr>
<tr>
<td>10</td>
<td>L N L N L</td>
<td>L D C 3 F E</td>
<td>3 6 C D E F</td>
<td>C 5 B 2 E D</td>
<td>2 5 B C D E</td>
</tr>
</tbody>
</table>

*Figure 11. Example of Set 1 and matching Set 4 items, alongside their template structure for Letter Number Sequencing task. 'L' represents a letter between A to F, 'N' represents a number between 1 to 9.*
**Arithmetic**

There were eight items in each set, progressing in difficulty from a two number equation to a four number equation with two mathematical functions (addition, subtraction, multiplication or division). An example of an easier item 1 equation and more difficult item 7 equation are shown in Figure 12.

Item equations were read aloud as a story, so it was expected the equation would be solved in the order it was presented aloud in the story, disregarding bracket rules for mathematical functions.

Matching for the second study day was achieved by keeping the equation the same but changing the numbers and the nouns in the story, for example an item about cats and biscuits was matched with an item about children and lollies (see Figure 12 for examples of how Set 1 and Set 4 items matched each other). For all items it was ensured numbers chosen made logical sense alongside the changed nouns.

![Table of Arithmetic items](image)

**Visual reproduction**

There were seven items in each set, they did not increase in difficulty as the set progressed. Each item had a unique base shape design (for example circle, rectangle, star), within this base shape there were other geometric elements placed on or near the underlying base shape (for example dots, lines, squiggles). In total each item design had a maximum of 10 elements, thus 10/10 was the maximum possible score per item.

Task matching for the second study day was achieved by rearranging the elements within the design to ensure equivalent difficulty (see examples Figure 13). Items were matched across study day 1 and 2, so Set 1 matches Set 4, Set 2 matches Set 5 etc.
Set 1, 2 and 3 all have the same base shape with similar but not exactly the same elements. Likewise, Set 4, 5 and 6 all have the same base shape with similar but not exactly the same elements (see examples Figure 14).

Figure 13. Example of two Visual Reproduction items and their corresponding matched item for the second study day (these images were taken from the administrators’ marking guide, the participants version had no labels or number marks).
Figure 14. Example of three Visual Reproduction items from one study day. Each item has different elements, but are based on the same base shape design (these images were taken from the administrators’ marking guide, the participants version had no labels or number marks).
Appendix H. Example of Spatial Span Instructions and Task

Set 1 – Task 4: Spatial Span

Instructions to Participants:

In this task I’m going to point to a sequence of squares and it’s your job to point to the same sequence in the same order as I did.

So if I did this [point to 5 1 8], what would you do? [Make sure the participant points to 5 1 8 in that order]. That’s right! [Move on] If the participant response is incorrect say “Not quite. Try again”. [Point to 5 1 8 and make sure the participant point to 5 1 8]. That’s right!

As we go through my list, the sequences will get longer, so just be ready for that.

Do you have any questions? [Answer any questions]

Ok, are you ready? Here’s the first sequence.

For research use only:

Note: Discontinue Rule – stop if participant gets three incorrect in a row.

<table>
<thead>
<tr>
<th>Item</th>
<th>Sequence (one per second)</th>
<th>✓ or ✗</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>5 8 4</td>
<td></td>
</tr>
<tr>
<td>Item 2</td>
<td>3 2 5</td>
<td></td>
</tr>
<tr>
<td>Item 3</td>
<td>5 2 3 4</td>
<td></td>
</tr>
<tr>
<td>Item 4</td>
<td>7 3 1 5</td>
<td></td>
</tr>
<tr>
<td>Item 5</td>
<td>5 6 3 7 8</td>
<td></td>
</tr>
<tr>
<td>Item 6</td>
<td>9 2 7 3 2</td>
<td></td>
</tr>
<tr>
<td>Item 7</td>
<td>6 8 1 2 9</td>
<td></td>
</tr>
<tr>
<td>Item 8</td>
<td>9 7 3 5 4 2</td>
<td></td>
</tr>
<tr>
<td>Item 9</td>
<td>3 8 1 2 7 8</td>
<td></td>
</tr>
<tr>
<td>Item 10</td>
<td>2 9 7 3 9 6</td>
<td></td>
</tr>
</tbody>
</table>

Total number correct:

68
Appendix I. Example of Letter Number Sequencing Instructions and Task

Set 1 – Task 9: Letter Number Sequencing

Instructions to Participants:

In this task I’m going to say a sequence of letters and numbers and you need to say them back to me, but with the numbers first in numerical order and the letters next in alphabetical order.

So if I said 4 D 2, you would say 2 4 D. The numbers first in numerical order and the letters next in alphabetical order.

Here’s another example: F 5 A. What would the answer be? [Participant should say 5 A F]. That’s right!

Here’s another example: B 9 E 3 [indicate for the participant to answer – 3 9 B E]. If answer is incorrect say “Not quite. The numbers were 9 and 3, so you’d list them first in numerical order, 3 then 9. The letters were B and E, so you’d list them next in alphabetical order, B E”.

Try another one: 6 C 7 B [indicate for the participant to answer – 6 7 B C].

As we go through my list, the sequences will get longer, so just be ready for that. Also, I will only be able to give you each sequence once.

Do you have any questions? [Answer any questions]

Ok, are you ready? Here’s the first sequence.

---

For research use only:

**Note: Discontinue Rule** – stop if participant gets three incorrect in a row.

<table>
<thead>
<tr>
<th>Item</th>
<th>Sequence (one per s)</th>
<th>Correct Answer</th>
<th>Participant’s sequence</th>
<th>✔️ or ✗</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>5 C F 2</td>
<td>2 5 C F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 2</td>
<td>D 7 3 A</td>
<td>3 7 A D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 3</td>
<td>E 9 B 3</td>
<td>3 9 B E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 4</td>
<td>F D 6 A</td>
<td>6 A D F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 5</td>
<td>5 F A 3 1</td>
<td>1 3 5 A F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 6</td>
<td>C 6 8 B 5</td>
<td>5 6 8 B C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 7</td>
<td>A 2 F 7 4</td>
<td>2 4 7 A F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 8</td>
<td>8 C 4 E 5</td>
<td>4 5 8 C E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 9</td>
<td>D F 9 B 4 A</td>
<td>4 9 A B D F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 10</td>
<td>D 6 C 3 F E</td>
<td>3 6 C D E F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total number correct:
Appendix J. Example of Arithmetic Instructions and Task

Set 1 – Task 13: Arithmetic

Instructions to Participants:

In this task I’m going to read a series of mathematical problems to you in the format of a story. You will then need to say the answer back to me.

Here’s an example:
A farmer has 10 horses but five run away. How many horses remain?
What would the answer be? [Participant should say 5]. That’s right!

Here’s another example:
If you have four friends and three family members at your dinner party, and have to provide each with a drink, how many drinks must you provide? [Let participant answer]
For this example the answer would be 7, as 4 plus 3 = 7.

As we go through my list, the problems will get more difficult, so just be ready for that. Also, I will only be able to give you each sequence once.
Do you have any questions? [Answer any questions]
Ok, are you ready? Here’s the first problem.

For research use only:

<table>
<thead>
<tr>
<th>Item</th>
<th>✓ or ✗</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
Appendix K. Example of Visual Reproduction Instructions and Task

Set 1 – Task 19: Visual Reproduction

Instructions to Participants:

You will be shown an image for 20 seconds and your task is to remember it. You will then be asked to draw the image from memory, and you will have 40 seconds to do this.

The positioning of the shapes or elements of the image are as important as getting the shape correct. The images will not become more difficult as we progress through the task.

Here is an example:

Do you have any questions? [Answer any questions]

Ok, are you ready?

Remember to LOOK ONLY and remember for the first 20 seconds. Here’s the first image.

For research use only:

Scoring will be 1 mark per correct item drawn as per the Visual Reproduction Resource.

<table>
<thead>
<tr>
<th>Item</th>
<th>Score /10</th>
<th>Item</th>
<th>Score /10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td></td>
<td>Item 5</td>
<td></td>
</tr>
<tr>
<td>Item 2</td>
<td></td>
<td>Item 6</td>
<td></td>
</tr>
<tr>
<td>Item 3</td>
<td></td>
<td>Item 7</td>
<td></td>
</tr>
<tr>
<td>Item 4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Visual reproduction marking

Some extra info around marking in addition to the guide in the researcher booklets.

Slight misses in the Ps drawing ability are allowed for full marks. For example, connection or intersection due to fast drawing is allowed. This is a memory task, so it is more about remembering the elements within the picture. Not people’s drawing ability.

Criteria for half marks

One of the below mistakes is allowed on an element. If two of these apply then the element is scored as zero

You may reward a half mark if the:

- Orientation of the element is correct but not the right way up e.g. ⭐ vs ⭐
- Location of the element is not within the correct part of the base shape (see below notes)
- Proportion of the element is slightly out – although this has to be lenient for drawing ability and time pressure (score as zero if significantly out of proportion)
- Shape is incorrect but everything else is right e.g. a coloured square instead of a coloured circle
- Quantity of dots, dashes, circles etc are incorrect but everything else is right (this criteria does not include the squiggles or bumps such as in item 1 in sets 2 & 5 as these are a somewhat random symbol)
- Opacity is incorrect but everything else is right e.g. ● vs ○

Base shapes:

- To score full marks on base shape, the shape must be the shape. But some changes to proportions, aspect ratios etc are ok. E.g., a slightly rectangle-looking square base shape.

Location (as above) of the element is not within the correct part of the base shape: refer to star image as an example of parts

Item 1: Star - element must be on the same part of base shape, 5 parts to base shape
Item 2 & 4: Circle/s - less than 90° from where element was in original image, 4 parts to base shape
Item 3: Rectangles - element must be on the same side of base shape, 8 parts to base shape
Item 5: Square - element must be on the same side of base shape, 4 parts to base shape
Item 6: Triangle - element must be on the same side of base shape, 3 parts to base shape
Item 7: Cross/plus - element must be on the same part of base shape, 4 parts to base shape

Arrows:

To score the full 1 mark for arrow elements they have to have the same arrowhead, as it is in the original. Not a triangle as the arrowhead, (even though that’s how some people draw their arrows).

1 mark:  

½ mark (if only arrowhead is wrong. If arrowhead is wrong AND incorrect length of arrow, location, orientation etc as above zero marks would be scored):  

72
### Appendix M. General Results of Full Standing Desk Study

<table>
<thead>
<tr>
<th>Task</th>
<th>Variable*</th>
<th>Significance Value of Main Effect of Condition</th>
<th>Significance Value of Main Effect of Time of Day</th>
<th>Significance Value of Interaction</th>
</tr>
</thead>
<tbody>
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<td>Cancellation</td>
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<td>.008</td>
<td>.837</td>
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<td>Coding</td>
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<td>Rapid Picture Coding</td>
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<td>.922</td>
<td>&lt;0.001</td>
<td>.958</td>
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<td></td>
<td>Number of Errors</td>
<td>.345</td>
<td>.210</td>
<td>.689</td>
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<td></td>
<td></td>
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<tr>
<td>CPT-AX</td>
<td>Average RT</td>
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<td>&lt;0.001</td>
<td>.417</td>
</tr>
<tr>
<td></td>
<td>Number Correct</td>
<td>.930</td>
<td>.803</td>
<td>.556</td>
</tr>
<tr>
<td>CPT-Inhibition</td>
<td>Average RT</td>
<td>.446</td>
<td>&lt;0.001</td>
<td><strong>.022</strong></td>
</tr>
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<td></td>
<td>Number Correct</td>
<td>.790</td>
<td>&lt;0.001</td>
<td>.579</td>
</tr>
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<td>Figural Intersection</td>
<td>Number Correct</td>
<td><strong>.008</strong></td>
<td>.030</td>
<td>.324</td>
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<td></td>
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<td>.309</td>
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<td><strong>Domain: Working Memory</strong></td>
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<td>Letter-number Sequencing</td>
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<td>Spatial Span</td>
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<td>&lt;0.001</td>
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<td>.415</td>
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<td>.089</td>
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<td>&lt;0.001</td>
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<td>Average Time to Complete</td>
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<td><strong>Domain: Executive Functioning</strong></td>
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<td>Trail Making</td>
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<td>&lt;0.001</td>
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<td>Verbal Fluency</td>
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